

*PROTOTIPO DI ATTUATORE MECCANICO PER SUPERFICI
ATTIVE IN ANTENNE PARABOLICHE*

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1. INTRODUZIONE

Una delle cause maggiormente penalizzanti nei confronti dell'efficienza delle antenne paraboliche comunemente usate in radioastronomia é la deformazione dello specchio primario dovuta alla gravitá. La struttura dell' antenna é sottoposta a carichi gravitazionali dipendenti dalla elevazione che causano deformazioni tali da alterare la forma, idealmente parabolica, dello specchio. Lo scarto quadratico medio delle deformazioni della superficie, rispetto ad un profilo parabolico perfetto, commisurato alla lunghezza d'onda di ricezione, fornisce l'indicazione di quanto l'efficienza teorica massima diminuisce.

Evidentemente questo effetto negativo sará tanto piú pesante quanto piú alta é la frequenza osservativa, perció, a tutti gli effetti, tale deformazione limita la massima frequenza usabile.

Per avere una idea quantitativa di quanto possa pesare l'effetto gravitazionale sull'rms complessivo della superficie primaria si possono utilizzare le misure di deformazione effettuate sull'antenna di Medicina al fine di valutarne l'efficienza; a 43GHz l'efficienza dovuta esclusivamente all'rms dei pannelli sarebbe il 26% (0.075 K/Jy), diminuisce al 12% considerando gli effetti della deformazione gravitazionale.

Nell'ambito di un progetto di miglioramento delle prestazioni della antenna, (Rif. 1), la compensazione delle deformazioni gravitazionali e il conseguente recupero del degrado di guadagno é uno degli obiettivi piú importanti da raggiungere. La soluzione adottata finora in alcuni radiotelescopi é di realizzare un progetto strutturale in cui la gravitá induca deformazioni che mantengano comunque parabolica la forma dello specchio alle varie elevazioni. Una antenna siffatta, cosiddetta omologa (Rif. 2), ha costi notevolmente superiori rispetto ad una a struttura classica e, soprattutto, tale soluzione non é applicabile all'esistente, come é il nostro caso. Attualmente in nessuna antenna non omologa é implementato un sistema di recupero delle deformazioni, solo il progetto del nuovo radiotelescopio di Greenbank (GBT project) prevede l'uso della cosiddetta "superficie attiva". É questa l'alternativa ad un progetto omologo, realizzabile anche su antenne giá esistenti: antenne di diametro considerevole, come sono quelle per radioastronomia, hanno lo specchio primario costituito di tanti pannelli (normalmente di qualche m² di area). Si puó pensare allora di renderli mobili in modo da mantenere parabolica la superficie, compensando le deformazioni prodotte dalla gravitá sulla struttura di sostegno a mano a mano che l' antenna cambia elevazione.

Sostanzialmente e` necessario un attuatore, l'elemento meccanico che consente la movimentazione, per ogni pannello costituente lo specchio, ovvero, nel nostro caso, circa 240 di questi elementi. E` evidente allora come, alla fattibilita` prettamente tecnica, un ruolo non trascurabile lo giuoca il fattore costo. Dal punto di vista realizzativo i principali vincoli di progetto sono l' affidabilita` del sistema nel suo complesso e le dimensioni contenute dell'attuatore.

Questo rapporto interno si occupa del primo passo sulla strada della realizzazione del sistema "superficie attiva". Sono stati progettati e costruiti due prototipi di attuatore meccanico per la

movimentazione dei pannelli della antenna di Medicina. L' idea e` quella di sottoporli a prolungati test di funzionalita` e affidabilita` in condizioni simili a quelle a cui sarebbero sottoposti in campo. Nei capitoli che seguono verra` descritto quindi il progetto del prototipo di attuatore e la sua realizzazione. Inoltre si tentera` una ipotesi di controllo della rete di comando attuatori.

2. DEFORMAZIONI GRAVITAZIONALI DELL'ANTENNA VLBI DI MEDICINA E SPECIFICHE DELL'ATTUATORE

Il primo passo necessario a definire delle specifiche di funzionamento dell'attuatore e' la conoscenza dell'entita` delle deformazioni cui e` soggetta la superficie da rendere "attiva".

A Medicina, all'epoca del rifacimento e riallineamento dello specchio primario dell'antenna parabolica (1989), furono fatte misure della posizione dei pannelli a diverse elevazioni. Una successiva elaborazione di queste misure ha consentito di conoscere l'entita` del massimo valore di deformazione sul totale dei pannelli a tutte le posizioni di interesse. In questo modo e` definibile, prevedendo un opportuno margine, la corsa meccanica dell'attuatore.

Sostanzialmente i risultati di queste misure hanno evidenziato che lo specchio primario ha le deformazioni maggiori agli estremi dell'intervallo di movimento in elevazione. Allo zenith esso si apre verso il basso, all'orizzonte la parte superiore cede in avanti mentre quella inferiore all'indietro. In ogni caso lo spostamento maggiore lo hanno i pannelli dell'anello piu` esterno ed esso e` stato misurato essere $\pm 3\text{mm}$ massimi rispetto alla posizione degli stessi all'elevazione di allineamento.

La valutazione dei carichi a cui l'attuatore verra` sottoposto e` inerente sia al peso proprio del pannello sia alla sollecitazione causata dal vento.

Ogni attuatore verra` montato tra il reticolare di sostegno dello specchio e specchio stesso; esso e` dunque in ambiente esterno, sottoposto a severe condizioni climatiche. Inoltre, dovendo mantenere fissa la lunghezza focale dell'antenna, si pone un vincolo alla massima dimensione assiale dell'attuatore, cioe` la dimensione parallela all'asse dell'antenna. Questa dimensione si configura a tutti gli effetti come uno spessore che dovra` essere recuperato sullo specchio secondario: i margini di manovra non sono ampi, ma vincolati a non piu` di 60-70mm.

A questo punto siamo in grado di dare delle specifiche costruttive, riassunte schematicamente nella tabella che segue

Specifiche attuatore

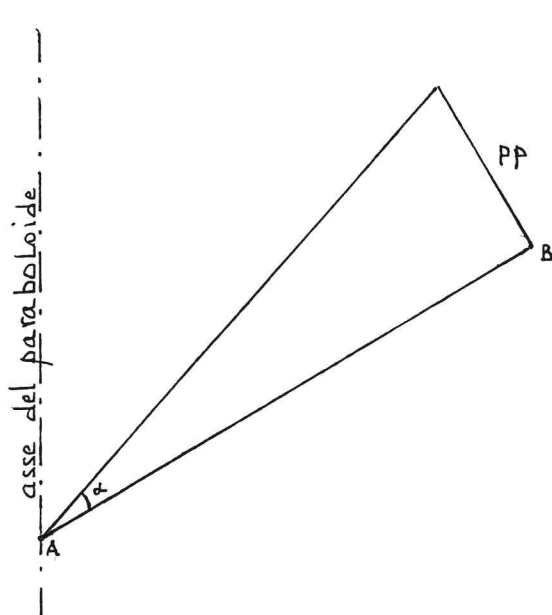
Corsa.....	$\pm 5\text{mm}$
Precisione di posizionamento.....	0.05 mm
Forza max.....	150 Kg
Carico max.....	500 Kg
Temperatura di funzionamento.....	-20/+50 °C
Dimensione assiale.....	60 mm
Tempo di ciclo.....	1.3 minuti

Tabella 1

Alcune di queste specifiche necessitano di un minimo di spiegazione.

La **precisione di posizionamento** deve essere scelta in modo da non influire sull'rms complessivo di superficie. In fase di allineamento i pannelli dello specchio vengono aggiustati, modificando la loro posizione lungo la componente perpendicolare

alla superficie, fino a portarli ad un esatto angolo rispetto all'asse del paraboloide e fissandoli definitivamente tramite bulloni. L'inserimento di un attuatore modifica la posizione del pannello lungo la medesima componente e dunque la sua precisione di posizionamento deve essere migliore rispetto alla intrinseca precisione dello strumento usato per l'allineamento. La nostra specifica di 0.05 mm (pp) corrisponde a 0.6 arcsec di errore (α), sull'anello piu` esterno, nell'angolo di allineamento, il che e` migliore della precisione di allineamento, 1 arcsec (Fig. 1).



B = punto di fissaggio pannello dell'anello esterno
 AB = linea di mira del teodolite (1775.6 mm)
 α = precisione di allineamento (1")
 pp = precisione di posizionamento

$$AB * \operatorname{tg} \alpha = pp$$

Fig. 1

La **forza max** prevista e' dovuta al peso del pannello (56Kg quello di dimensioni maggiori, con superficie di 5m²) piu` l'esposizione al vento a 60Km/h, che corrisponde alle estreme condizioni operative dell'antenna. E` inteso che tale valore deve essere sopportato sia lato pannello che lato reticolare. L'incidenza di carico del vento non e` facilmente precisabile, si fara` riferimento a quanto descritto in Rif.3 pag.7 e 8 ove si da` una stima del carico dovuto alla velocita` del vento nei limiti di sopravvivenza antenna. Tale valore verra` poi scalato tenendo presente che il carico varia col quadrato della velocita`. Da un valore di pressione di carico di 1776N/m² a 180Km/h si ottiene a 60Km/h su 5m² di superficie una forza pari a circa 100Kg che, aggiunti ai 56 del pannello nel caso peggiore, fornisce 156Kg. Questo nell'ipotesi, peggiorativa ma possibile in alcuni casi operativi, di presa frontale al vento da parte del pannello.

Il **carico max** e` il valore di forza a cui deve resistere l'attuatore in condizioni di sopravvivenza antenna, cioe` nel caso di vento a 180Km/h, sempre da entrambi i lati. Il calcolo

fornirebbe circa 900Kg ma, in questo caso, l'antenna e` considerata in stow position cosicche` non e` realistica la presa frontale al vento. Un valore piu` praticabile di carico in questa situazione e` stato allora assunto pari a 500Kg.

Il **tempo di ciclo**, ovvero il tempo impiegato dall'attuatore per percorrere tutta la corsa, e` stato imposto sulla base delle seguenti considerazioni. Normalmente la sistemazione della superficie attiva puo` essere fatta mentre l'antenna cambia sorgente e l'entita` dello spostamento dei pannelli sara` tanto maggiore quanto diversi sono i valori di elevazione iniziale e finale; nel caso estremo di passaggio dall'orizzonte allo zenith, o viceversa, l'antenna impiega circa 2.5 minuti, in questo tempo la superficie deve essere corretta. Si consideri inoltre che possa essere necessaria anche una ricerca di zero, allora, nel caso peggiore, necessitano due corse complete dell'attuatore (due cicli). Si imponga quindi 1.3 minuti come tempo ciclo.

Oltre alle specifiche occorre aggiungere che l'attuatore,

- deve essere meccanicamente interfacciabile con l'esistente, ovvero devono rimanere invariate le posizioni delle viti di fissaggio alla reticolare. In questo modo si evita di dover interporre una piastra di adattamento tra il supporto sulla struttura e l'attuatore, guadagnando spazio sulle dimensioni assiali dello stesso
- deve essere meccanicamente irreversibile, cosi` da mantenere la posizione anche in mancanza di alimentazione motore o in caso di rottura di qualche componente elettrico di comando
- deve avere un sistema antirotazione dell'albero di uscita. Questo e` importante, all'atto dell'allineamento dello specchio primario, per evitare di rovinare la camma di trasmissione del moto e, in normali condizioni operative, a impedire carichi torsionali sui supporti dei pannelli
- deve essere costituito da materiali inattaccabili dagli agenti atmosferici
- deve essere perfettamente stagno l'insieme attuatore-scatola elettrica, comprendente motore, encoder, elettronica.
- deve soddisfare al requisito, da noi voluto, di contenere all'interno della scatola anche la parte elettronica di controllo e di potenza. Questo da un lato semplifica il cablaggio tra tutti gli attuatori dislocati sull'antenna e dall'altro evita eventuali problemi di generazione disturbi (RFI).

Dalla lettura di queste specifiche e vincoli e` evidente quanto accurato deve essere il progetto e la caratterizzazione dell'oggetto in questione. In particolare evidenza vogliamo porre il problema inerente l'affidabilita` dell'insieme attuatore meccanico-elettronica di controllo, vero cuore del sistema. Come gia` detto esso verra` racchiuso in una scatola di dimensioni contenute e verra` replicato per alcune centinaia di esemplari (consideriamo ovviamente anche una implementazione sull'antenna gemella di Noto). Da questo punto di vista un ruolo non indifferente lo gioca il fatto che l'oggetto si trova in ambiente esterno a grandi altezze e, a montaggio avvenuto, l'accessibilita` all'elemento non sara` delle piu` semplici. E` chiaro che

malfunzionamenti generalizzati possono condurre ad una disposizione dello specchio "a caso" nell'intervallo di variabilita` della corsa dell'attuatore, quindi cio` che piu` conta e` ottenere un posizionatore a bassa manutenzione e di operativita` talmente buona da rendere remota la necessita` di interventi.

Ne consegue che test prolungati hanno soprattutto lo scopo di verificare questa importante specifica.

3. PROGETTO E REALIZZAZIONE MECCANICA DEL PROTOTIPO DI ATTUATORE

3.1 PARTI COMPONENTI

Sulla base delle specifiche descritte nel capitolo precedente e` stato progettato e realizzato il prototipo di attuatore lineare in due esemplari. Il complessivo e` mostrato nelle fig. 2a ed 2b, in cui possiamo identificare i seguenti elementi costitutivi:

- a) organo di movimentazione (motore)
- b) organo meccanico di trasmissione del moto (attuatore) e il relativo sensore di zero
- c) sistema di rilevamento dello spostamento (encoder)
- d) scheda elettronica di controllo e relativo driver di potenza

Poniamo subito in evidenza che e` stato realizzato l'obiettivo di contenere il sistema nelle dimensioni previste; l'insieme attuatore-scatola elettrica contiene tutti gli elementi descritti, atti a realizzare la funzionalita` voluta.

Entriamo ora nel dettaglio di ciascun elemento.

a) Motore

Le caratteristiche dell'organo di movimentazione devono essere basso costo e bassa manutenzione.

Il mercato propone diversi tipi di motori, in corrente continua con spazzole e brushless, stepping, sincroni, asincroni.

Non fa al caso nostro il motore cc a causa della presenza di spazzole e della necessita` di un complesso sistema di controllo. Quelli di tipo brushless hanno eccessive prestazioni rispetto alle nostre richieste ed anche il costo e` maggiore rispetto ad altri tipi.

Particolarmente indicato e` invece il motore stepping, semplice d'uso, con bassa manutenzione e costo contenuto, non ha bisogno di un rivelatore di posizione. Anche il motore sincrono puo` fare al caso nostro, fornisce una buona coppia anche a basso numero di giri, necessita di scarsa manutenzione, non ha bisogno di un driver elettrico; necessita invece del rivelatore di posizione.

Il motore asincrono, invece, e` stato scartato perche` ha prestazioni insufficienti in generale e soprattutto nelle funzioni di start/stop.

Sulla base di queste indicazioni i due prototipi di attuatore sono stati equipaggiati uno con motore stepping (modello Sanyo-step-syn 103-770-6) ed uno con motore sincrono (modello Oriental Motor 2CSM-101).

b) Attuatore

E' l'elemento mediante il quale il moto rotatorio del motore e' trasformato in moto lineare del pannello. Per ottenere questo si e' usato un classico accoppiamento vite senza fine-ruota elicoidale con rapporto di riduzione 100. Sull'albero motore e' fissata, tramite giunto, la vite senza fine a filetto trapezio, mentre sulla ruota elicoidale e` flangiata una boccola su cui a

sua volta e` calettato un rullo. Quest'ultimo lavora all'interno di un albero scanalato a doppia elica, destrorsa per 270° della sua circonferenza e sinistrorsa per i rimanenti 90° . L'aver reso solidale il rullo con la ruota elicoidale fa si` che ponendo in rotazione quest'ultima esso possa scorrere, rotolando, nella scanalatura riportata sull'albero con cio` trascinando linearmente l'albero stesso e quindi il pannello. Il gioco esistente tra rullo e scanalatura e` stato contenuto in 0.03mm, per rispettare la precisione di posizionamento e per evitare che il vento faccia oltremodo vibrare ciascun pannello. In verita` si poteva evitare cio` costruendo un sistema precaricato ma questo avrebbe complicato il progetto rendendo impossibile il contenimento delle dimensioni.

La corsa utile del pannello si sviluppa sulla parte destrorsa della scanalatura, per 270°, mentre se, per un qualunque motivo, il pannello va a fine corsa, il rullo si trova in corrispondenza della parte sinistrorsa e comincia a ridiscendervi trascinando all'indietro il pannello. Questa soluzione, oltre a prevenire l'uso di fine corsa, da` maggiore respiro al progetto evitando l'eventuale situazione in cui il motore continua a spingere in posizione di fermo.

Pertanto gli elementi di progetto a cui si e' posta maggiore attenzione sono l'ottenimento della irreversibilita` dell'accoppiamento, in quanto si vuole essere certi che in caso di mancanza alimentazione o di malfunzionamento/rottura del driver la posizione meccanica venga mantenuta "naturalmente" e la possibilita`, da parte dell'insieme meccanico, di lavorare sempre in sicurezza, evitando che il malfunzionamento dell'apparato motore/comando possa portare il pannello in posizione di sforzo ai limiti di corsa. La prevenzione di un tale effetto con qualsiasi altro sistema di conversione del moto avrebbe necessitato l'uso di rivelatori di fine corsa, incrementando cosi` il numero di particolari, gli ingombri, l'affidabilita` totale del sistema, la parte elettrica di controllo. La soluzione adottata previene tutti questi inconvenienti.

E` stato inoltre inserito nella scatola meccanica un sensore di zero. Esso e` necessario perche` i rivelatori di posizione sono incrementali in entrambe le soluzioni, conteggio del numero di passi nella soluzione stepping, encoder nella soluzione sincrono, ed e` invece assolutamente necessario ricostruire e riposizionare, all'occorrenza, una parabola di riferimento, che sara` quella all'atto dell'allineamento iniziale dello specchio. Il modello di sensore e` E2E con diametro M8 della Omron ed i dati generali di funzionamento sono forniti in Appendice. Un eventuale black out del sistema che mandasse fuori posizione tutto lo specchio, oppure anche solo la necessita` di garantire sicurezza di risultato nella ricostruzione della superficie parabolica, potrebbero essere recuperati ritrovando prima di tutto la "parabola di zero" e riposizionando poi lo specchio ai valori relativi alla elevazione corrente. Tutta l'operazione impiegherebbe un tempo piuttosto basso, comparabile di volta in volta con tempi di cambio sorgente, cambio nastro, tempi di attesa nella schedula osservativa.

c) Encoder

Se si usa il motore sincrono l'utilizzo dell'encoder e` necessario per chiudere il loop di posizione . Il modello scelto e` l' HP HEDS-5400 per le sue piccole dimensioni, basso costo, elevato intervallo di temperatura di funzionamento. La risoluzione e` 400 passi a giro, proprio come si ha nella soluzione con stepping motor. Per i dettagli si veda il data sheet riportato in Appendice.

d) Scheda elettronica di controllo e relativo driver di potenza

Per effettuare i test sul prototipo si e` cercato di scegliere componentistica, tra le tante possibili, prontamente disponibile, di basso costo e di uso pressochè immediato, cioè con minimo sforzo dal punto di vista software. La scelta e` caduta su prodotti della Cybernetic microsystems.

Questo costruttore fornisce un evaluation kit completo di microprocessore (CY545), controllore di rete per interfaccia RS232 (CY233) e software per comandare sistemi a stepping motor. In più, sulla scheda, c'è lo spazio disponibile per aggiungere il driver di potenza.

Il micro CY545 consente di impostare tutti i parametri necessari e sufficienti per pilotare lo stepping in termini di rampa di acc./dec., numero di step, modo di funzionamento (continuo o a step singolo, assoluto o relativo), velocità e direzione di movimento, gestione di limiti di corsa.

L' interfaccia di rete CY233 può gestire fino a 255 sistemi stepping con una unica seriale su personal computer (si veda al paragrafo 3.3 l'utilizzazione di questo componente).

La parte di potenza e` costituita dal controllore L297 e dal vero e proprio integrato di potenza L6203, entrambi della SGS. Il primo "dialoga" con le uscite del micro CY545 e contiene tutta la logica digitale per fornire al successivo stadio, costituito essenzialmente di transistori di potenza, la sequenza corretta di alimentazione degli avvolgimenti del motore e la forma d'onda necessaria a realizzare i passi.

Nelle figure 3a,b,c sono riportate le varie parti elencate, mentre in Appendice si troveranno i data sheet dei componenti menzionati e una succinta descrizione della filosofia di funzionamento dei driver per motori stepping.

L'alimentazione, a bassa tensione, e` fornita tramite trasformatore a partire dalla 220V, realizzando così l'isolamento galvanico.

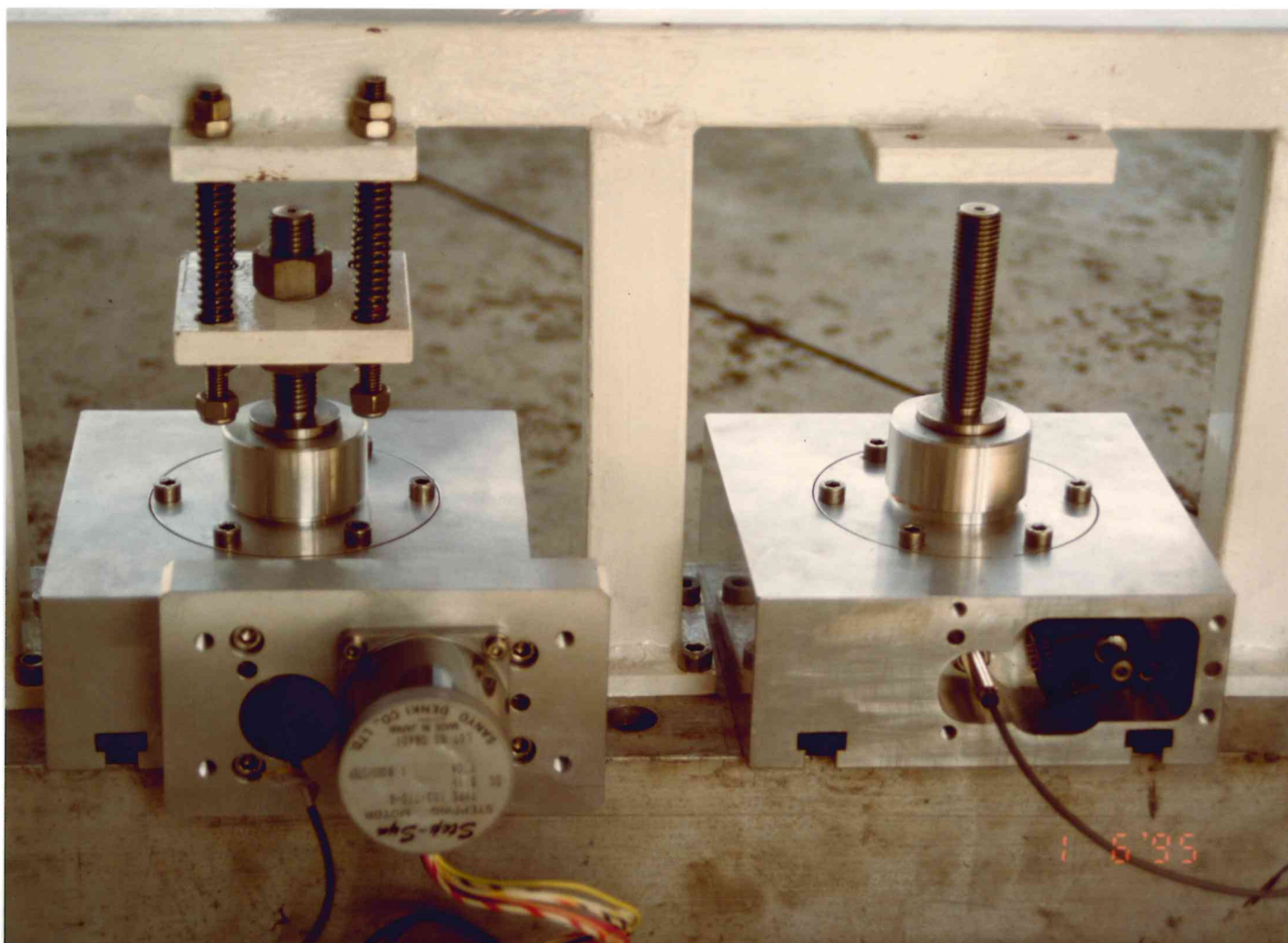


Fig. 2a

Vista dei due prototipi. Da quello a destra sono visibili il sensore di zero e l'encoder. In quello a sinistra e` montata anche la piastra su cui e` avvitato il motore (stepping) e su cui viene connessa la scatola dell'elettronica (vedi fig. 2b). In questa foto il prototipo di sinistra e` anche meccanicamente collegato a quattro molle che hanno lo scopo di simulare il pannello da muovere.

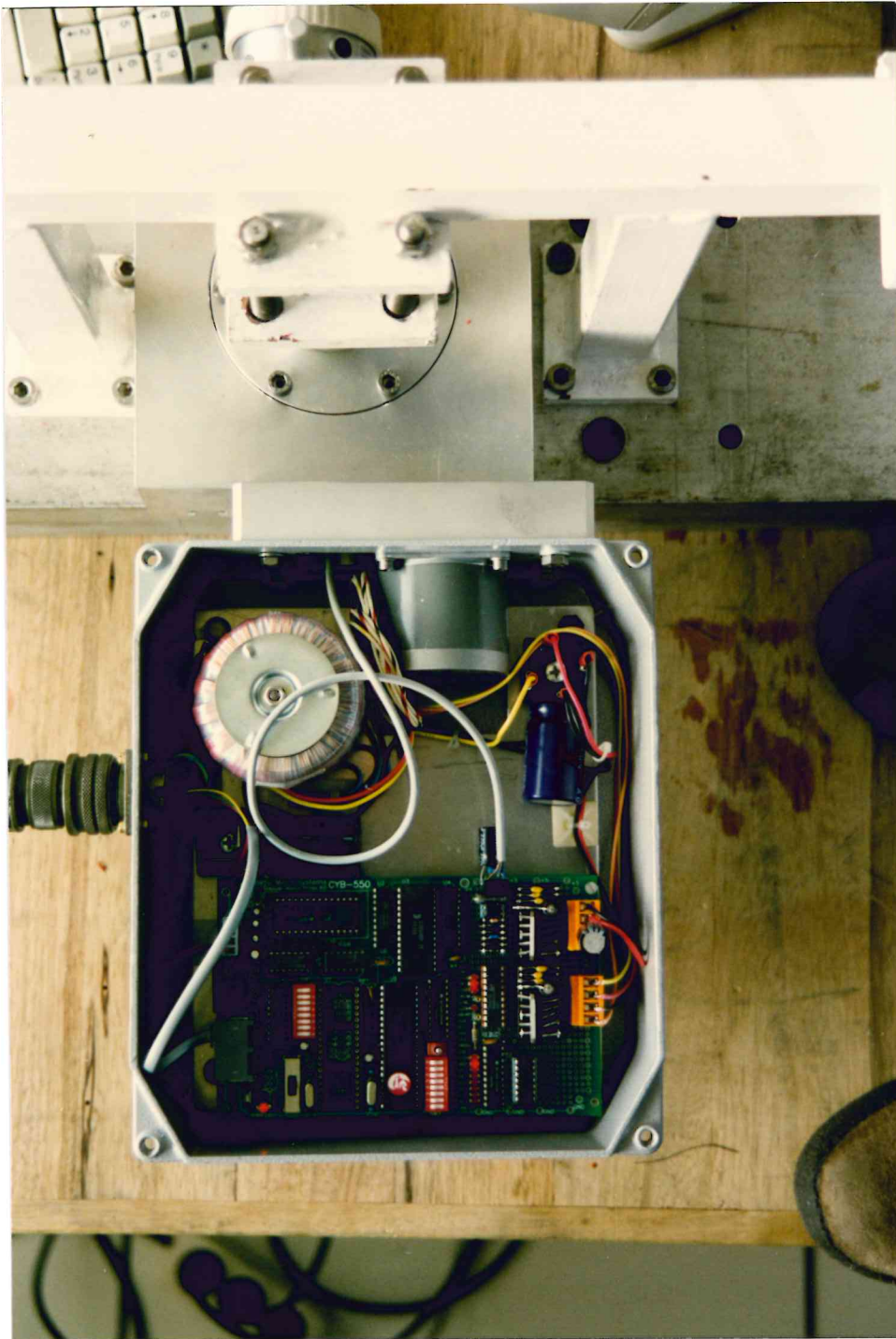


Fig. 2b

Vista dall'alto della scatola contenente l'elettronica e il driver di potenza connessa all'attuatore. Si notano, il motore (stepping), il trasformatore di alimentazione, l'evaluation kit della Cybernetic Micro System e il connettore che porta la 220V e i segnali digitali di I/O.

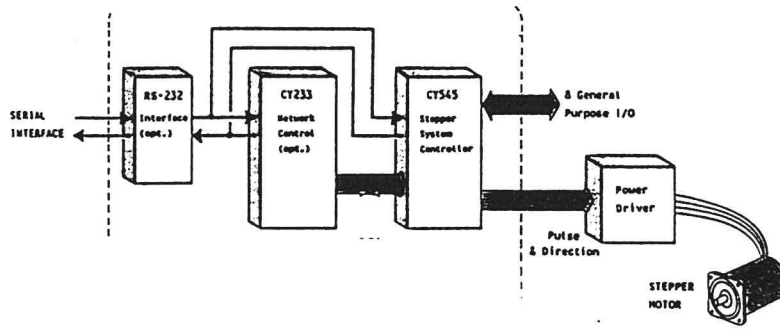


Fig 3a - Controllo e potenza per motore stepping

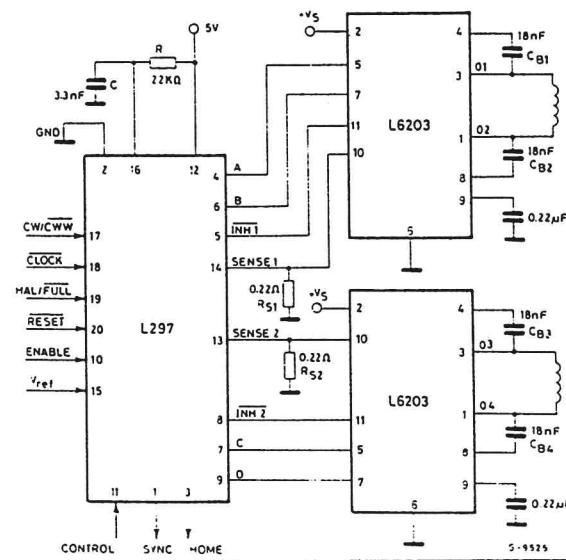


Fig 3b - Power driver

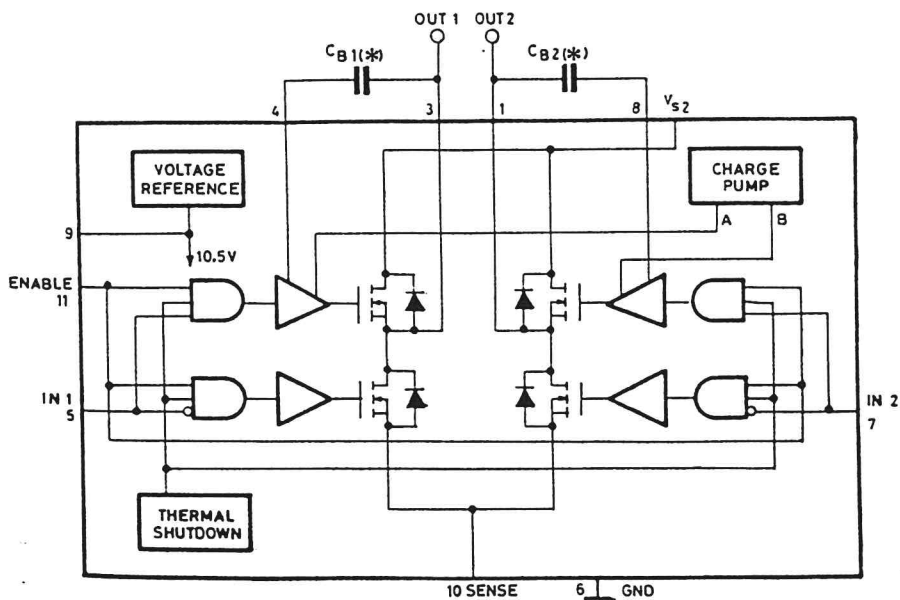


Fig 3c - L 6203 integrated circuit

3.2 DIMENSIONAMENTO DEL SISTEMA

Il sistema e' schematizzato come dalla figura che segue, evidenziando le parti del riduttore.

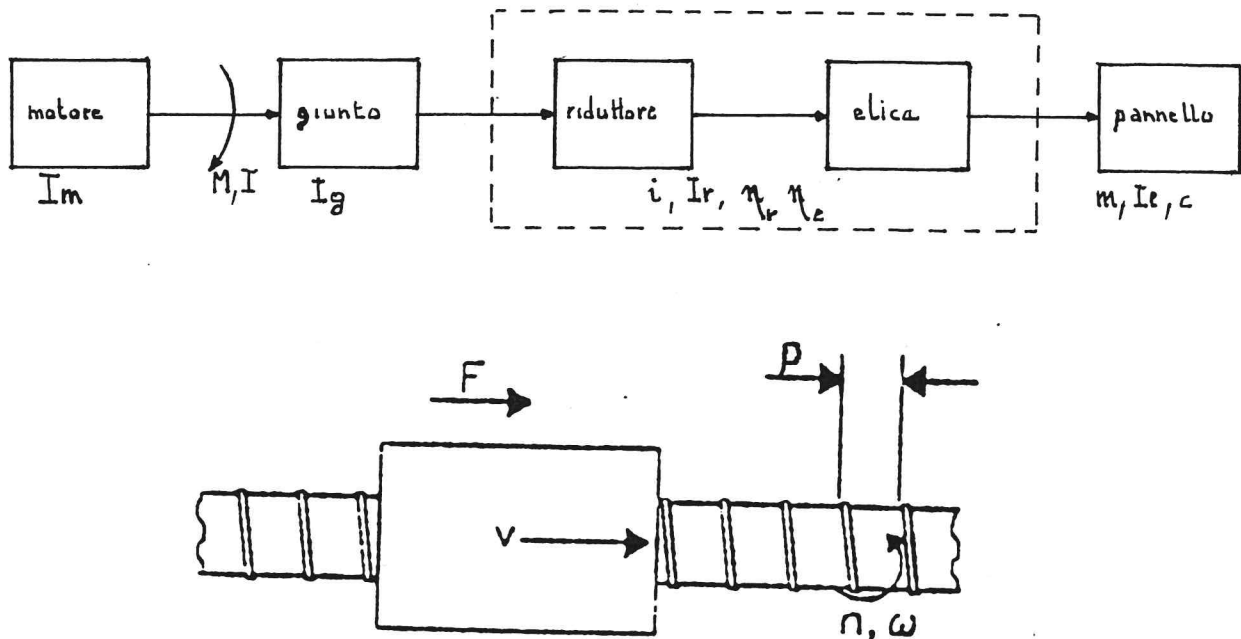


Fig. 4

I dati di partenza sono:

- Passo d'elica dell'albero scanalato $p=13.33\text{mm}$ ($\eta_e=0.85$)
- Corsa utile dell'albero scanalato $c=10\text{mm}$
- Rapporto di riduzione $i=100$ ($\eta_r=0.24$)
- Massa pannello $m=56\text{Kg}$
- Forza di gravita` sul pannello $F_g=550\text{N}$
- Forza dovuta al vento $F_v=981\text{N}$
- Inerzia giunto $I_g=2.52 \cdot 10^{-6} \text{Kgm}^2$ (giunto Oldham $\phi=25$)
- Inerzia riduttore $I_r=7.32 \cdot 10^{-6} \text{Kgm}^2$
- Precisione di posizionamento $\Delta_s=0.05\text{mm}$

Da questi, considerando anche la tabella 1, si puo` inoltre ricavare nelle normali condizioni operative,

- Carico= 1500N
- Rendimento totale $\eta_t=0.204$ ($=\eta_e \cdot \eta_r$)
- Inerzia del carico $I_1 = m(p/2\pi)^2 = 150 \cdot (13.33 \cdot 10^{-3}/2\pi)^2 = 675 \cdot 10^{-6} \text{Kgm}^2$
- Inerzia totale al motore $I = I_g + I_r + I_1/i^2 = 9.9 \cdot 10^{-6} \text{Kgm}^2$
- Coppia all'albero motore $M = \frac{(F_g + F_v) \cdot p}{2\pi \cdot i \cdot \eta_t} = \frac{1500 \cdot 1.333}{2\pi \cdot 100 \cdot 0.204} = 15.6 \text{Ncm}$

- Risoluzione minima $\leq \frac{\Delta_s * i * 270}{c} = \frac{0.05 * 100 * 270}{10} = 135^\circ/\text{step}$
del motore

Tutti questi dati hanno bisogno di una qualche descrizione e spiegazione.

Il passo dell'elica di 13.33mm e` stato cosi` scelto perche` la camma di movimento deve percorrere l'intera corsa di 10mm anziche` in un giro completo, in 3/4 di giro in quanto il quarto rimanente consente il ritorno all'indietro del pannello.

Il rapporto di riduzione 100 si spiega considerando la necessita` di avere una assoluta irreversibilita` del sistema, questo non e` limitante stante le caratteristiche di bassa velocita` richiesta.

Il valore di inerzia del riduttore lo si ottiene dai cataloghi, noti le dimensioni dello stesso e delle parti commerciali usate (vite, cuscinetti).

Il calcolo della risoluzione minima da` una idea della classe di motori da usare. Il valore trovato consente una ampia facolta` di scelta perche` comuni motori commerciali hanno risoluzione enormemente migliore.

A questo punto si hanno due casi, a seconda del tipo di motore scelto

a) SOLUZIONE CON MOTORE PASSO PASSO TIPO SANYO-STEP-SYN 103-770-6

L'inerzia di questo motore si accoppia molto bene con quella totale all'albero, il suo valore e' infatti $10.5 * 10^{-6}$ Kgm².

Inoltre, verra` usato a 1KHz (1000 passi al secondo), risoluzione di 400 passi per ogni giro del motore (quindi con velocita` di 2.5 giri/sec) e funzionamento half-step, cioe` con rotazione di 0.9° per ogni passo (vedi data sheet allegato).

La velocita` massima di posizionamento del pannello la si ottiene da quella del motore riportandola all'albero lento e trasformandola da giri/sec in mm/sec sapendo che in un giro l'albero lento percorre 13.33mm

$$v_{\max} = \frac{v_{\text{mot}} * p}{i} = \frac{2.5 * 13.33}{100} = 0.33 \text{ mm/sec}$$

Da qui si puo` ora calcolare il tempo di ciclo e confrontarlo con la specifica richiesta (vedi Tab.1). Supponendo un tempo di accelerazione, uguale a quello di decelerazione, pari a 2 sec si puo` calcolare l'accelerazione

$$a = v_{\max} / T_{\text{acc}} = 0.165 \text{ mm/sec}^2$$

lo spazio percorso nel tempo T_{acc} e`

$$s_{\text{acc}} = 0.5 * a * T_{\text{acc}}^2 = 0.33 \text{ mm}$$

che corrisponde a 742 passi del motore. Infatti $270^\circ/c$ sono i gradi/mm all'albero lento mentre $270^\circ*i/c$ lo sono all'albero motore. Dividendo questo per la risoluzione, $0.9^\circ/\text{step}$, si ottengono il numero di passi/mm che compie il motore.

$$\frac{270*i}{c*0.9} = 2250 \text{ step/mm}$$

Il tempo impiegato a velocità costante è

$$T = \frac{C - S_{\text{acc}} * 2}{V_{\text{max}}} = \frac{10 - 0.6}{0.33} = 28.3 \text{ sec}$$

e quindi il tempo di ciclo è

$$T_{\text{ciclo}} = T + 2 * T_{\text{acc}} = 32.3 \text{ sec}$$

Il valore trovato è ben inferiore a 1.3 minuti il che, se necessario, da agio a scegliere valori di T_{acc} anche più elevati di 2 sec.

Si vuole ora calcolare il valore della coppia dovuta alla accelerazione, che deve essere aggiunta a quella richiesta a regime. Il motore, in fase di accelerazione, deve vincere l'inerzia del carico e quella di se stesso, questo valore deve poi essere moltiplicato per l'accelerazione angolare al fine di ottenere la coppia d'accelerazione. L'accelerazione angolare si calcola da quella lineare trasformando $0.165\text{mm}/\text{sec}^2$ nel suo corrispondente in rad/sec^2 : 0.165mm corrispondono a 371 step ($2250 * 0.165$) e a 333.9° ($371 * 0.9$), ovvero 5.83 radianti. Allora,

$$\text{Inerzia totale al motore } I_t = (9.9 + 10.5) * 10^{-6} = 20.4 * 10^{-6} \text{ Kgm}^2$$

$$\text{Accelerazione angolare } a_\omega = 5.83 \text{ rad}/\text{sec}^2$$

$$M_{\text{acc}} = I_t * a_\omega = 0.1 \text{ Ncm}$$

che è completamente trascurabile rispetto alla coppia richiesta a regime di 15.6Ncm. La coppia fornibile dal motore è abbondantemente superiore a quest'ultimo valore, anche considerando che nel funzionamento half-step il valore fornito di coppia massima, riferentesi al funzionamento full step, deve essere dimezzato.

La risoluzione data da questo motore e` 150 volte meglio di quella necessaria da specifica (Tab.1), infatti sta nel rapporto $135^\circ/0.9^\circ$. Si ha,

$$\Delta s = \frac{0.05}{135/0.9} = 3.3 \cdot 10^{-4} \text{ mm}$$

Per concludere possiamo dire che tutte le specifiche richieste sono soddisfatte da questo tipo di motore, rimarrebbero unicamente alcune considerazioni sulla potenza richiesta dal carico e fornibile dall'azionamento motore/driver. Non e' pero` semplice in questa sede farle perche` per i motori stepping la potenza richiesta dipende fortemente dal tipo di driver usato e anzi la potenza persa da quest'ultimo sara` senz'altro ben superiore a quella richiesta al carico. Comunque la potenza necessaria all'albero motore e`

$$P = M \cdot v_{\text{mot}} \cdot 2\pi = 2.5 \text{ Watt}$$

b) SOLUZIONE CON MOTORE SINCRONO MODELLO ORIENTAL MOTOR 2CSM-101

La sua inerzia e` pari a $16 \cdot 10^{-6} \text{ Kgm}^2$. La velocita` del motore a 50Hz e` 60 RPM, cioe` 1 giro/sec. Quindi

$$v_{\text{max}} = \frac{v_{\text{mot}} \cdot p}{i} = 0.13 \text{ mm/sec}$$

$$I_t = 25.9 \cdot 10^{-6} \text{ Kgm}^2$$

Dal data sheet (vedi) si evince che questo motore puo` accelerare in un brevissimo lasso di tempo, 25msec al massimo, se il carico inerziale e` inferiore al massimo consentito (ed e` il nostro caso), cosicche`

$$a_0 = 2\pi \cdot 1 / 0.025 = 251 \text{ rad/sec}^2$$

$$M_{\text{acc}} = I_t \cdot a_0 = 6.5 \text{ Ncm}$$

non trascurabile rispetto alla coppia di regime di 15.6 Ncm. Questo motore fornisce proprio 22 Ncm pilotato a 110V, un valore molto risicato rispetto al necessario, questo potrebbe darci dei problemi all'atto dei test.

Il tempo di ciclo, data l'alta accelerazione, e` sostanzialmente il tempo a velocita` costante e quindi vale

$$T_{\text{ciclo}} = \frac{10}{0.13 \cdot 60} = 1.3 \text{ minuti}$$

in accordo con la specifica.

Per quanto riguarda la risoluzione, con questo tipo di motore occorre un rivelatore di posizione. L'encoder scelto e` il tipo HP HEDS-5540 con forme d'onda a 100 impulsi a giro. Come e` usuale per questi sistemi, viene generato un passo ogni fronte di salita e di discesa delle due forme d'onda di eccitazione e quindi si ottengono 4 impulsi ogni periodo ovvero 400 impulsi a giro. Pertanto, rimanendo comuni gli altri parametri, il valore di risoluzione e` identico alla soluzione precedente.

La potenza all'albero motore e`

$$P = (M + M_{acc}) \cdot 1 \cdot 2\pi = 1.4 \text{ Watt}$$

Questo tipo di motore puo` fornire fino a 1.8 Watt di potenza (vedi data sheet in Appendice).

3.3 TOPOLOGIA DI INTERCONNESSIONE E SCHEMA DI CONTROLLO REMOTO

In questo paragrafo cerchiamo di fissare le idee su ipotesi di interconnessione elettrica tra gli attuatori montati sulla antenna e sulla filosofia di controllo remoto della rete che ne consegue. Prima di tutto e` opportuno mostrare, fig. 5, la disposizione dei pannelli sulla antenna.

Essi sono disposti su sei corone circolari concentriche, numerate da 2 a 7 in figura, ciascuna dimensionalmente identificata dal raggio della circonferenza esterna. La circonferenza 1 identifica i punti di attacco dei pannelli ai supporti piu` vicini al centro dello specchio.

Gli ultimi quattro anelli constano di 48 pannelli ciascuno, mentre i primi due di 24 ognuno. In totale abbiamo 240 pannelli. I supporti sono invece 288 e corrispondono a tutti gli incroci tra circonferenze e lato radiale del pannello (in figura ne sono indicati sette con dei pallini lungo un raggio dello specchio primario). Tuttavia, gia` da ora, escludiamo la correzione dei punti di attacco afferenti alla circonferenza 1. Rimangono percio` 264 attuatori, eventualmente riducibili a 240 escludendo anche la correzione dei supporti della circonferenza 2. Cio` e` lecito dopo aver verificato che le deformazioni di quei punti non influenzano l'rms complessivo. Come vedremo avere un numero di dispositivi da comandare inferiore a 256 ci sarebbe molto comodo da un punto di vista pratico.

L'indicazione dei raggi di ciascuna circonferenza consente di calcolare le metrature di cavo necessario per interconnettere gli attuatori a seconda della topologia scelta.

All'interno di una filosofia a bus i percorsi possibili sono, in linea di principio, moltissimi, noi ci limiteremo a tre possibili scelte confrontando tra loro i pro e contro.

Da un punto di vista del sistema completo l'idea e` quella di avere un personal computer che impartisce la posizione a ciascuna unita` di attuazione riferendosi ad una tabella di posizioni precostituita, in funzione dell'elevazione; la nuova posizione e`

accompagnata da un indirizzo e i bytes così costituiti sono disponibili sull'intera rete. Ad ogni unità è assegnato un indirizzo e dunque solo quello che riconoscerà sulla rete il proprio effettuerà lo spostamento indicato. È da rimarcare il fatto che ciascuna unità di attuazione è un dispositivo intelligente, nel senso che la parte elettronica consta del driver per pilotare il motore, del controllore di movimento e dell'interfaccia di rete, il tutto è quindi autosufficiente una volta nota la posizione comandata: occorrerà quindi distribuire sulla antenna, oltre la alimentazione primaria, una linea di trasmissione seriale, per esempio standard 485, al fine di comunicare le posizioni. È prevista anche la possibilità di inviare un comando comune agli attuatori, per esempio contrassegnato da un "indirizzo speciale" condiviso da tutti, mediante il quale si impone la ricerca di zero, ovvero si comandano tutti i pannelli nella posizione che hanno all'atto dell'allineamento, che è la posizione di riferimento. L'host computer inoltre controlla la posizione di ciascun pannello interrogando periodicamente le unità di attuazione. Questo viene ottenuto direttamente dal sensore di posizione nel caso della soluzione a motore sincrono, dal controllore del moto nel caso stepping motor. Da un punto di vista pratico non è possibile connettere direttamente tutte le unità di attuazione all'host, occorre prevedere dei ripetitori di linea atti a distribuire la comunicazione a gruppi di unità.

I criteri per scegliere un soddisfacente sistema di controllo e di interconnessione sono,

- a) minor quantità possibile di cavo, non tanto per ragioni economiche quanto di semplicità della rete
- b) semplicità e affidabilità della connessione tra attuatori, tra rete e ripetitore di linea e facile sostituzione di questi quando necessario
- c) ridurre al minimo eventuali emissioni di disturbi (RFI)
- d) ridurre al minimo gli effetti negativi sull'rms di superficie dovuti a non funzionamento di uno o più attuatori o del ripetitore di linea
- e) minimizzare il consumo di potenza elettrica per unità di attuazione

Per quanto riguarda il requisito c) esso è già soddisfatto dal fatto che la parte motore e il suo driver di potenza sono confinati nello stesso punto ove è posto l'organo meccanico di movimento cosicché il cavo di potenza, uno dei maggiori imputati nelle emissioni RFI, è cortissimo e racchiuso, assieme al motore, in una scatola schermata. In più, questa soluzione evita che la consistente metratura di cavo dislocata nello specchio primario debba implicare elaborate e costose schermature.

Nelle figure 6,7,8 sono mostrati tre possibili tipi di interconnessione. Caratteristica comune a tutti è che la totalità degli attuatori deve essere suddivisa in gruppi, questo

perche` ogni ripetitore di linea puo`gestire su bus un numero limitato di dispositivi, nel nostro caso fino a 32.

Allora nella soluzione di fig.6 la interconnessione si sviluppa sulle circonferenze considerando 11 gruppi, ed altrettanti ripetitori di linea, da 24 attuatori ciascuno. La lunghezza totale di cavo si valuta sommando tutte le circonferenze ed aggiungendo, per ogni gruppo, la lunghezza per connettere il ripetitore a quel gruppo. In totale si ottiene circa 500m di cavo. Un lato negativo di questa soluzione e` che se dovesse andare in avaria un ripetitore relativo alle circonferenze piu` esterne gli attuatori inamovibili sarebbero tutti relativi a pannelli ove la deformazione e` piu` alta.

Nella soluzione di fig.7 il sistema e` composto da 12 gruppi da 22 attuatori, non 24 per non distruggere la topologia sull'ultimo gruppo, e in questo caso il cavo circola dal punto R0, ove e` collocato il ripetitore, fino al ventiduesimo dispositivo del gruppo a cui corrispondono circa 54m di cavo. Il totale necessario e` dunque 648m. I lati positivi di questa soluzione sono che si hanno spezzoni di cavo di interconnessione di lunghezza costante e che i gruppi sono costituiti da dispositivi inerenti a tutte le circonferenze cosicche` il degrado di rms e` indipendente da quale ripetitore e` in avaria. Lati negativi sono la necessita`di un ripetitore in piu` e piu` cavo rispetto alla soluzione precedente.

Nella soluzione di fig.8 infine si fa capo a una sola circonferenza a cui afferiscono radialmente, con la propria tratta di connessione, tutti gli attuatori. A differenza delle topologie precedenti qui le interconnessioni tra ripetitore e attuatori del gruppo sono concentrate in una scatola posta sulla circonferenza. La lunghezza complessiva di cavo necessaria e` circa 1000m e i gruppi possono essere scelti come nel caso di fig.7 avendone pero`, come unico vantaggio, la equa distribuzione di dispositivi. Lati negativi di questa scelta sono la notevole quantita` di cavo necessaria e spezzoni di cavo di diversa lunghezza.

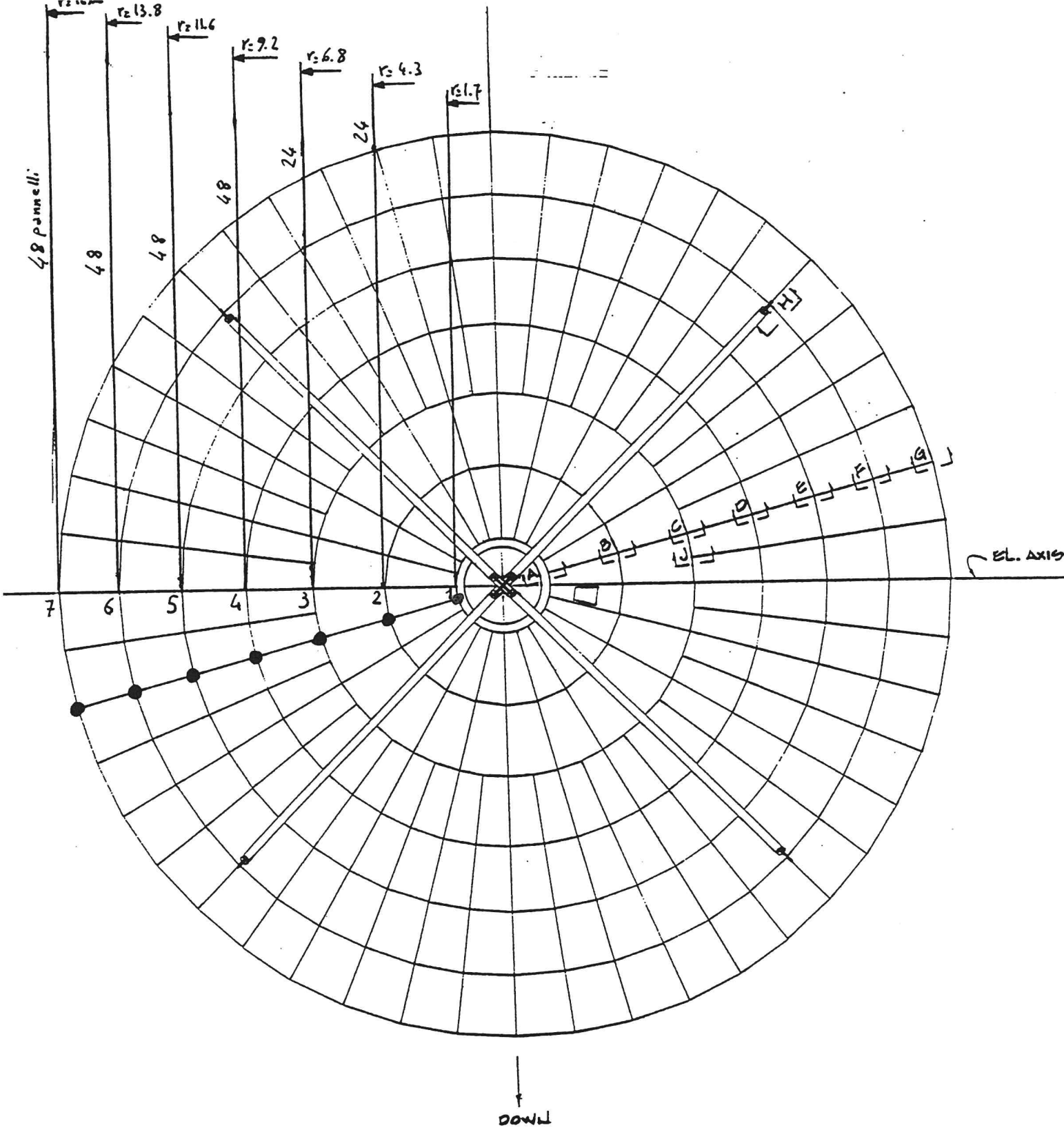
In fig.9 e` indicato lo schema a blocchi di principio del controllo distribuito di tutti gli attuatori. Sono mostrati il computer centrale e i ripetitori RS485, dislocati sull'antenna in corrispondenza della vertex room, in numero di 11 o 12 a seconda della topologia scelta ed le 264 unita` di attuazione poste sotto lo specchio primario. I collegamenti di interconnessione riportati costituiscono le topologie descritte.

Schematicamente possiamo dire che il protocollo di comunicazione tra computer e unita` di attuazione consta di almeno quattro bytes inviati dal PC (indirizzo+codice comando+2 bytes per il parametro del comando) e almeno due bytes di risposta dall'unita` di attuazione (la posizione), non necessariamente occorre rispedire l'indirizzo. Per una velocita` di comunicazione di 19200 bit/sec il tempo necessario al comando ed alla risposta di tutte le unita` (10 bit per ogni byte di cui uno di parita`, moltiplicato per 264) considerando che esistono anche tempi, non trascurabili, di protocollo del computer, e` stimabile a 10 sec, di molto inferiore al tempo di ciclo previsto.

L'interfaccia di rete puo` condividere fino a 255 dispositivi afferendo ad una unica seriale. Ecco spiegato il motivo della convenienza di ridurre a 240 il numero di attuatori.

In fig.10 e` descritta l'unita` di attuazione nei casi di motore stepping e di motore sincrono. Nel primo il controllore motore fornisce valore e tipo di rampa di accelerazione/decelerazione, velocita`, numero di passi per raggiungere la posizione. Nel secondo caso il controllore motore confronta la posizione comandata con quella rivelata dall'encoder e, a seconda che la differenza sia positiva o negativa, attiva uno degli switch (CW o CCW) per applicare potenza al motore (110 V) nella direzione corretta. In questo caso si ha un anello chiuso di posizione, nel precedente, invece, la posizione ritornata al computer e` quella relativa al numero di passi forniti allo stepping dal suo controllore.

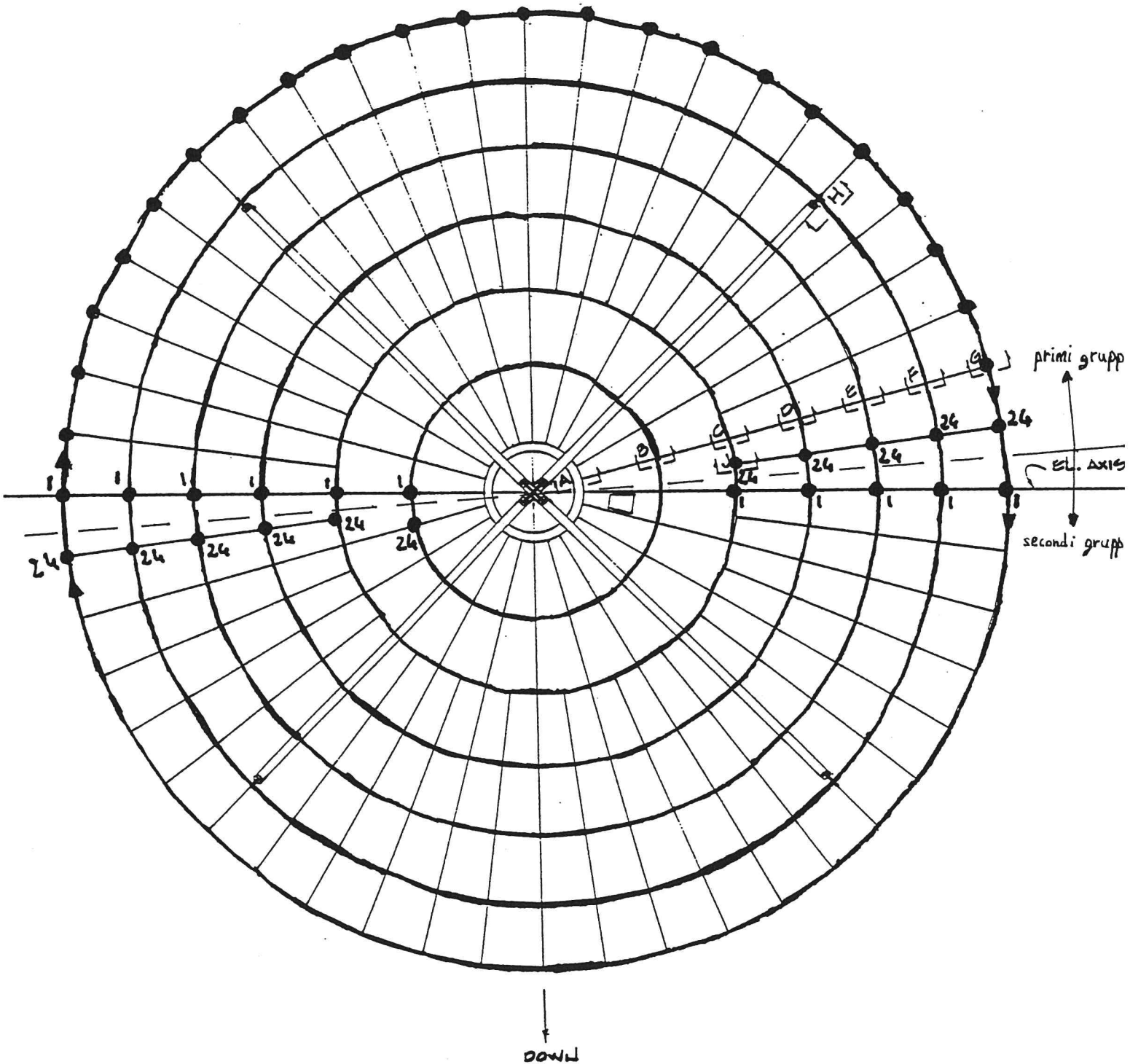
Per concludere questo paragrafo facciamo una breve considerazione relativa al requisito e). Esso potrebbe, a prima vista, sembrare non vincolante stante le basse potenze in gioco evidenziate nel paragrafo relativo al dimensionamento del sistema. La scheda che utilizzeremo nella fase di test per il controllo e il pilotaggio del prototipo di attuatore con motore stepping, aggiunto il consumo del motore, necessita di poco meno di 30W. Moltiplicato per 250 attuatori si ottengono circa 7.5kW! Una oculata scelta di questa parte del sistema probabilmente, secondo una nostra prima stima, potrebbe far risparmiare circa meta` di questo valore.



PLAN VIEW OF REFLECTOR PANELS

SCALE : $\frac{1}{8}'' = 1'-0$

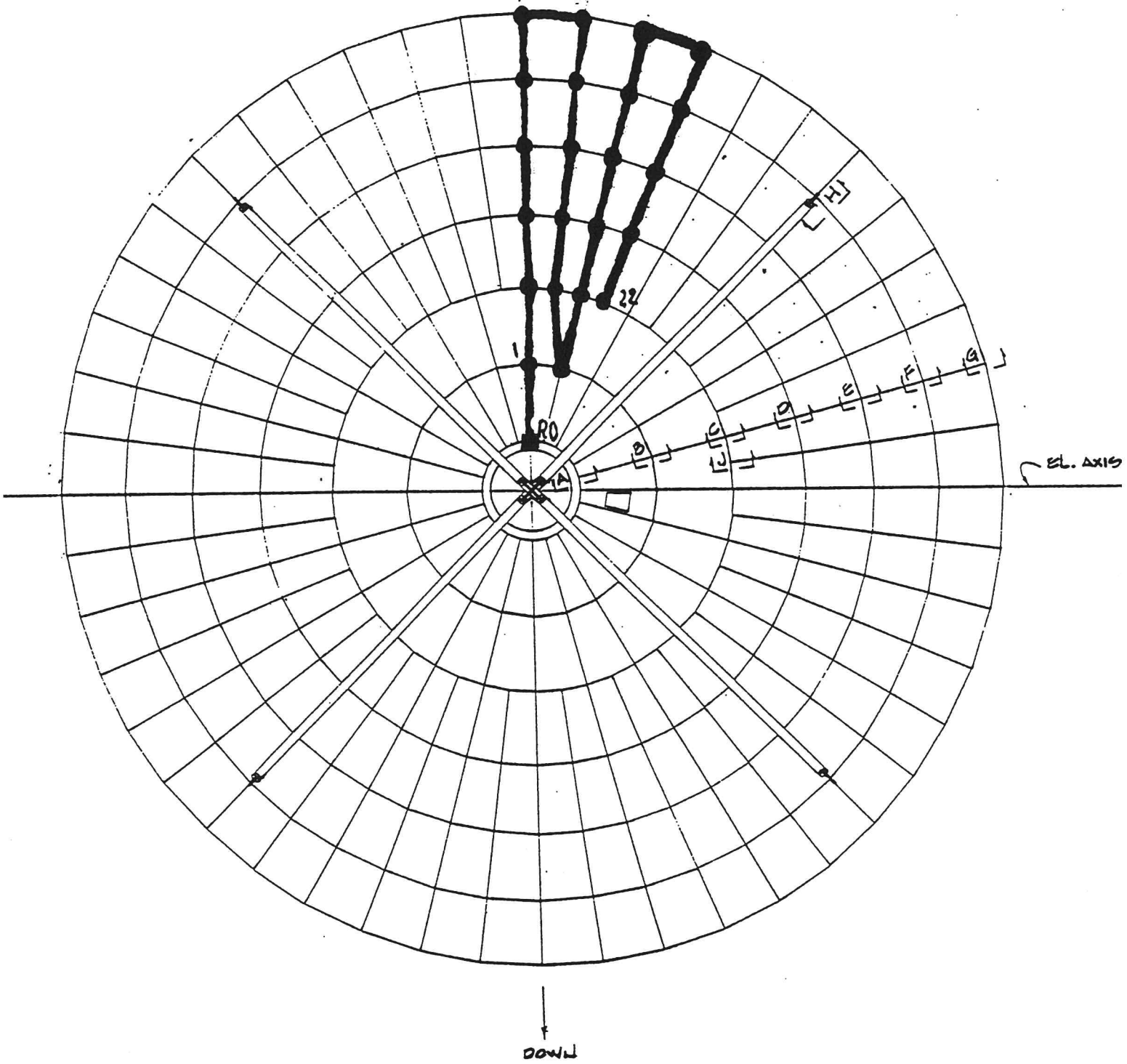
Fig.5



PLAN VIEW OF REFLECTOR PANELS

SCALE : 1/8" = 1'-0

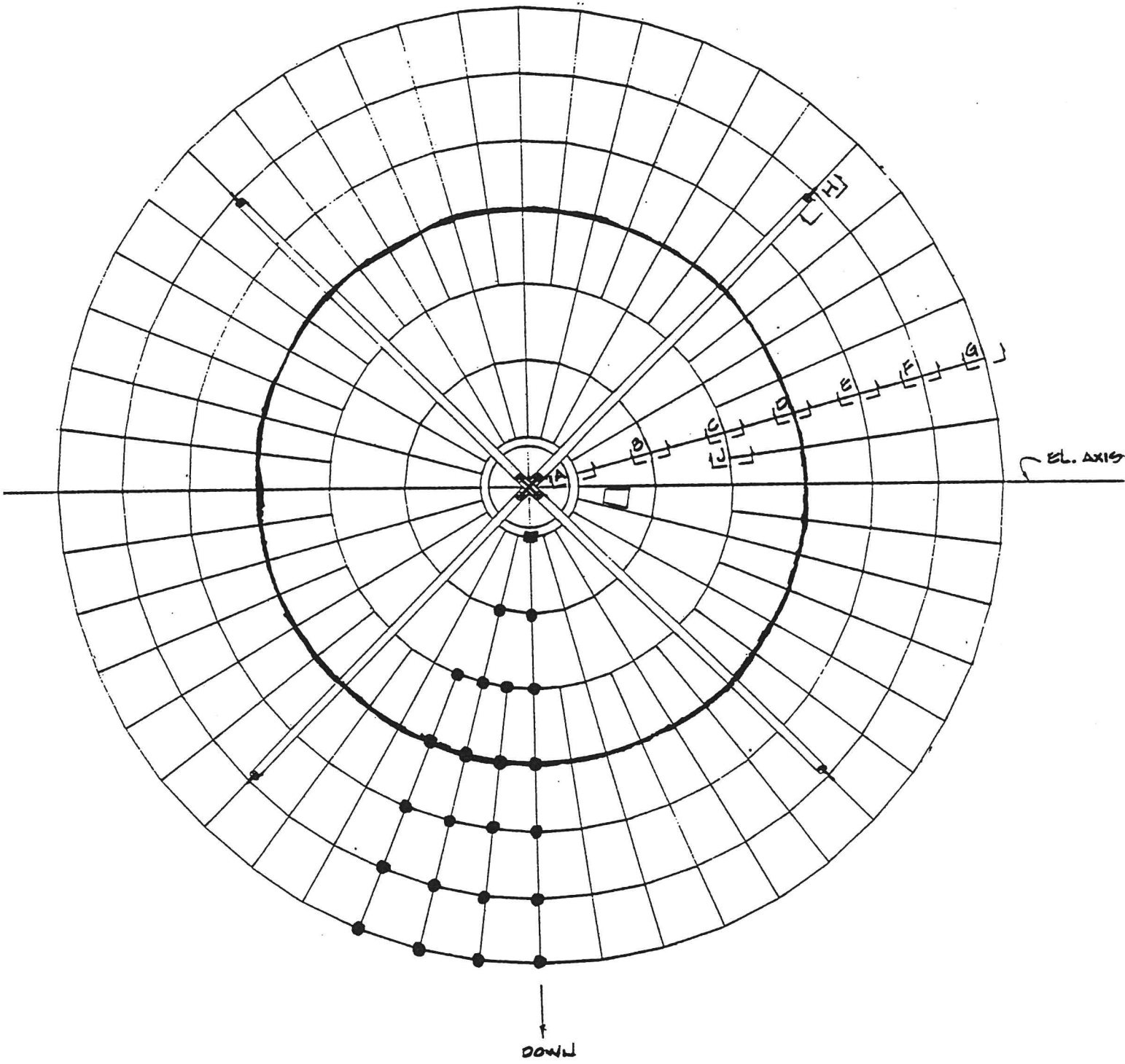
Fig. 6



PLAN VIEW OF REFLECTOR PANELS

SCALE : 1/8" = 1'-0"

Fig. 7



PLAN VIEW OF REFLECTOR PANELS

SCALE : 1/8" = 1'-0

Fig. 8

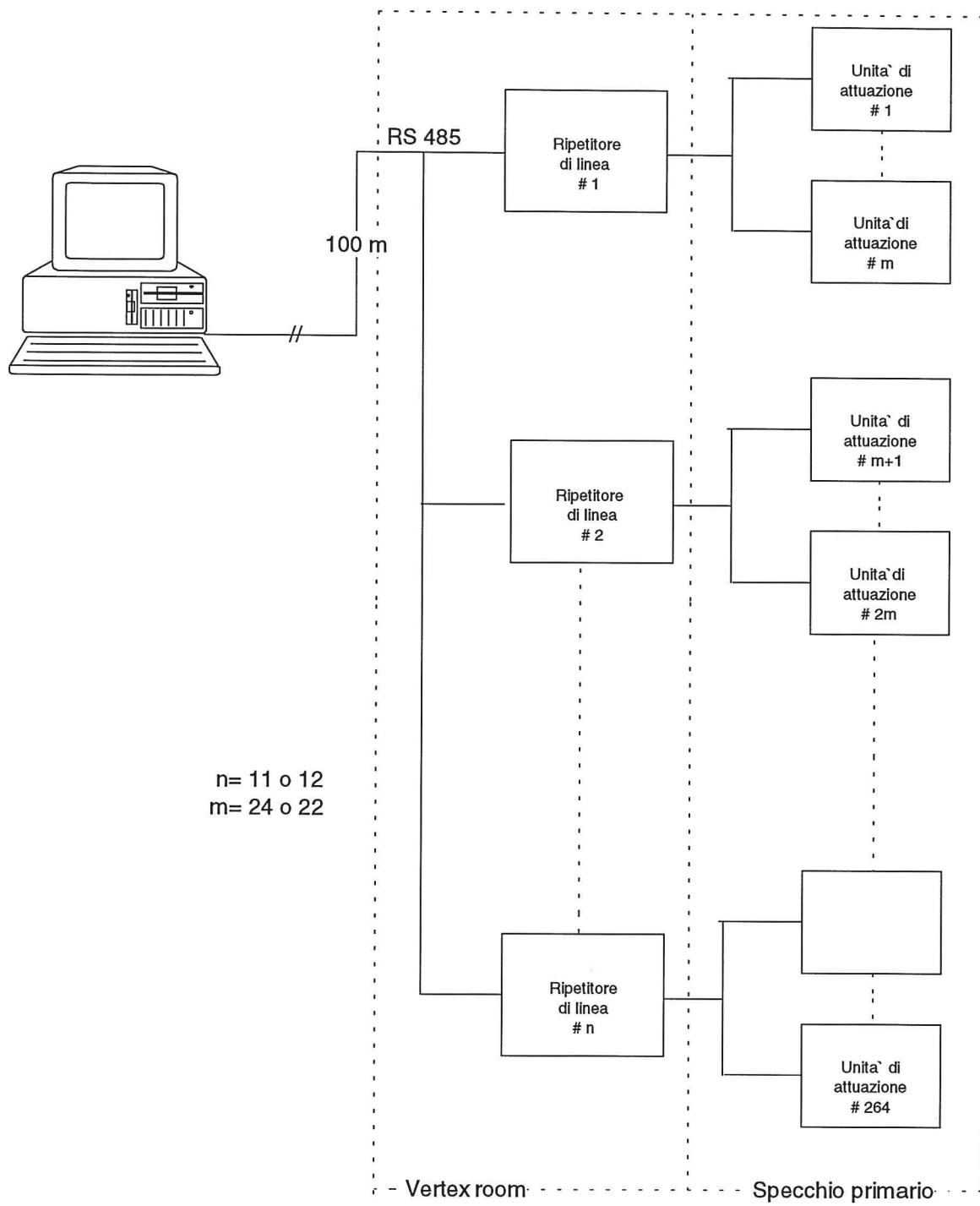
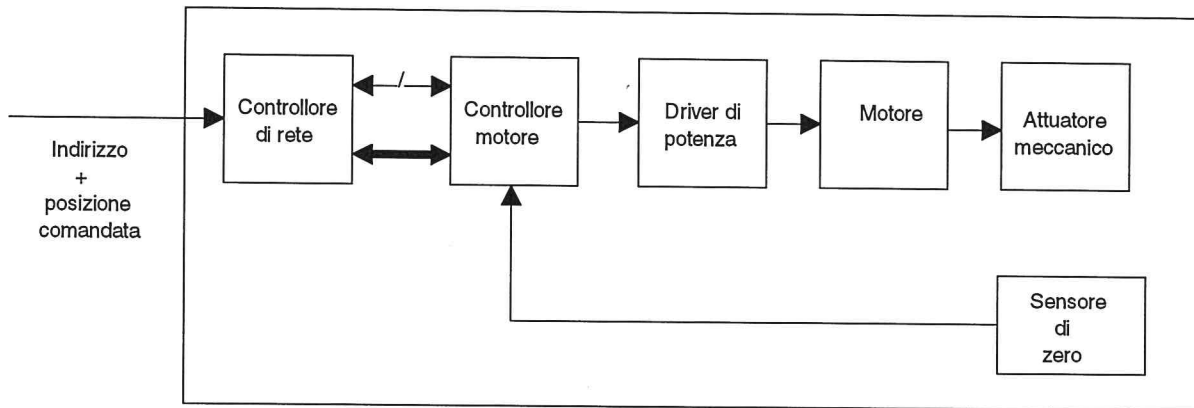


Fig. 9



UNITA' DI ATTUAZIONE CON STEPPING MOTOR

UNITA' DI ATTUAZIONE CON MOTORE SINCRONO

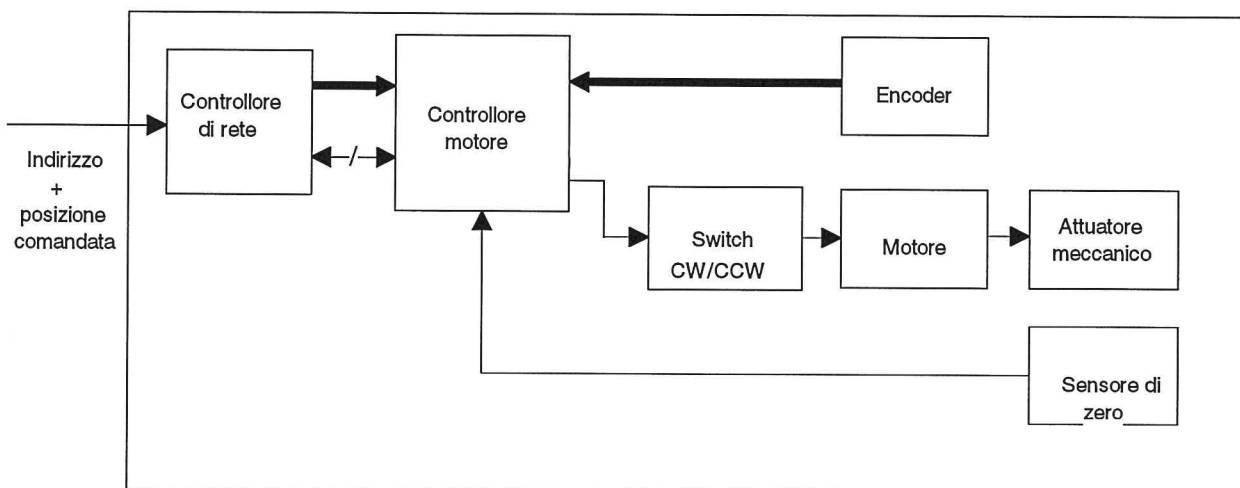


Fig. 10

3.4 STIMA DI COSTO DELL'ATTUATORE

Dato che, nella sua realizzazione definitiva, saranno necessari piu` di duecento attuatori per ogni antenna non e` di poco rilievo il costo unitario prevedibile. A questo proposito si puo` tentare una stima di questo parametro a partire dai componenti commerciali che lo costituiscono, dal materiale costruttivo e dal costo di lavorazione e montaggio. Dal punto di vista delle parti commerciali occorre dividere le due soluzioni adottate.

a) soluzione con motore passo-passo

- motore stepping bassa potenza.....	25000
- motore stepping alta potenza (in alternativa).....	(63000)
- sensore di zero.....	30000
- driver del motore e parte di potenza.....	24000
- controllore di rete CY233.....	37000
- controllore del moto CY545.....	60000
- alimentazione.....	30000
- scheda elettronica.....	40000
- connettore militare.....	30000

Totale 276000

Il totale qui e` fatto considerando il motore stepping di bassa potenza, tuttavia e` stato aggiunto anche il costo di uno piu` potente nel caso in cui i test mostrassero la insufficienza del primo tipo. Il costo del driver piu` la parte di potenza e` stato fatto considerando l'uso degli integrati L297 (in quantita` di 1 per attuatore) e L6203 (in quantita` di 2). La alimentazione comprende il trasformatore (ricordo che la alimentazione principale distribuita a tutti gli attuatori sara` 220V alternati) e la parte elettrica di raddrizzamento e livellamento della continua. La scheda elettronica consta del circuito stampato e le parti elettriche accessorie ai controllori. Il costo per componente vale per una quantita` di 500 pezzi alla data di fine 1995.

b) soluzione con motore sincrono

- motore sincrono.....	100000
- sensore di zero.....	30000
- encoder.....	60000
- controllore di rete CY233.....	37000
- alimentazione.....	30000
- scheda elettronica.....	40000
- connettore militare.....	30000

Totale 327000

Qui sensore, alimentazione, connettore sono del tutto uguali al caso precedente. La parte di driver, compresa nella voce scheda elettronica, consta di un contatore avanti/indietro e un transistor di potenza che serve a comandare un rele` che inverte

il moto del motore per raggiungere la posizione comandata. L'aumento del totale e` dovuto essenzialmente all'encoder, in piu`, e al motore.

A questi costi occorre naturalmente aggiungere quello della parte meccanica la cui valutazione non e` semplice. Stante l'alto numero di attuatori necessario potrebbe essere ipotizzabile ottenere la scatola per fusione, ma stimarne in questa sede il costo dell'operazione, e se questo e` competitivo con una realizzazione non pressofusa non e`, al momento, a noi noto.

4. RIFERIMENTI

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APPENDICE

Quick Assembly Two and Three Channel Optical Encoders

Technical Data

HEDS-5500/5540
HEDS-5600/5640
HEDM-5500/5600

New

mm, 2 channels

Shaft Diameter	
01 - 2 mm.	11 - 4 mm
02 - 3 mm	14 - 5 mm
03 - 1/8 in.	12 - 6 mm
04 - 5/32 in.	13 - 8 mm
05 - 3/16 in.	
06 - 1/4 in.	

mm, 2 channels

Shaft Diameter	
05 - 3/16 in.	11 - 4 mm
06 - 1/4 in.	12 - 6 mm
07 - 5/16 in.	13 - 8 mm
08 - 3/8 in.	
09 - 1/2 in.	
10 - 5/8 in.	

Features

- Two Channel Quadrature Output with Optional Index Pulse
- Quick and Easy Assembly
- No Signal Adjustment Required
- External Mounting Ears Available
- Low Cost
- Resolutions Up to 1024 Counts Per Revolution
- Small Size
- -40°C to 100°C Operating Temperature
- TTL Compatible
- Single 5 V Supply

Description

The HEDS-5500/5540, HEDS-5600/5640, and HEDM-5500/5600 are high performance, low cost, two and three channel optical incremental encoders. These encoders emphasize high reliability, high resolution, and easy assembly.

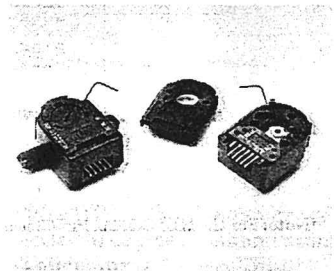
Each encoder contains a lensed LED source, an integrated circuit with detectors and output

circuitry, and a codewheel which rotates between the emitter and detector IC. The outputs of the HEDS-5500/5600 and HEDM-5500/5600 are two square waves in quadrature. The HEDS-5540 and 5640 also have a third channel index output in addition to the two channel quadrature. This index output is a 90 electrical degree, high true index pulse which is generated once for each full rotation of the codewheel.

The HEDS series utilizes metal codewheels, while the HEDM series utilizes a film codewheel allowing for resolutions to 1024 CPR. The HEDM series is not available with a third channel index.

These encoders may be quickly and easily mounted to a motor. For larger diameter motors, the HEDM-5600, and HEDS-5600/5640 feature external mounting ears.

The quadrature signals and the index pulse are accessed through five 0.025 inch square pins located on 0.1 inch centers.



Standard resolutions between 96 and 1024 counts per revolution are presently available. Consult local Hewlett-Packard sales representatives for other resolutions.

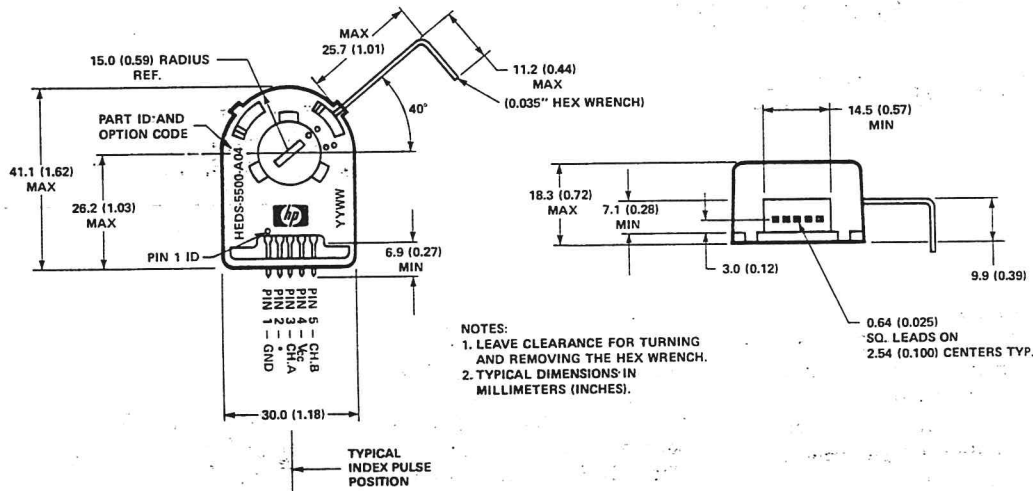
Applications

The HEDS-5500, 5540, 5600, 5640, and the HEDM-5500, 5600 provide motion detection at a low cost, making them ideal for high volume applications. Typical applications include printers, plotters, tape drives, positioning tables, and automatic handlers.

ESD WARNING: NORMAL HANDLING PRECAUTIONS SHOULD BE TAKEN TO AVOID STATIC DISCHARGE.

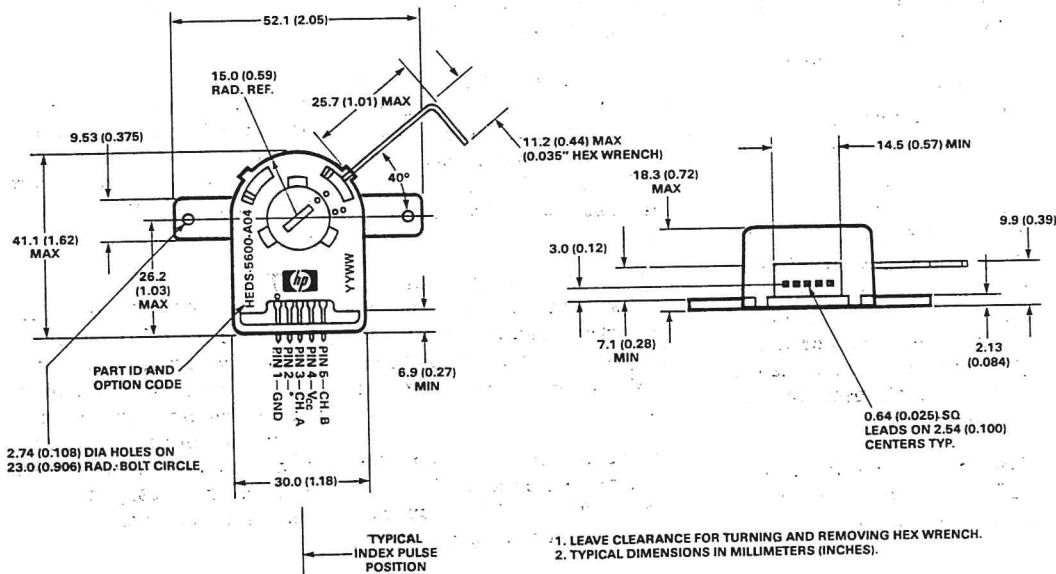
Package Dimensions

HEDS-5500/5540



*Note: For the HEDS-5500, Pin #2 is a No Connect. For the HEDS-5540, Pin #2 is CH. I, the index output.

HEDS-5600/5640



*Note: For the HEDS-5600, Pin #2 is a No Connect. For the HEDS-5640, Pin #2 is CH. I, the index output.

Theory of Operation

The HEDS-5500, 5540, 5640, and HEDM-5500 translate the rotary shaft into either a two or three-channel digital output.

As seen in the block diagram, these encoders contain a Light Emitting Diode (LED) as their light source. The LED is collimated into a parallel beam by means of a single lens located directly opposite the emitter. The integrated detector consists of an array of photodetectors and processing circuitry which produce the digital output.

The codewheel rotates the emitter and detector light beam to be interrupted by the pattern of space bars on the codewheel. The photodiodes which sense the interruptions are arranged in a pattern that corresponds to the radius and design of the codewheel. These detectors are also spaced such that the period on one pair of photodiodes corresponds to the distance between the adjacent pair of space bars. The photodiode outputs are then fed through the processing circuitry to produce the A, A-bar and B, B-bar outputs for channels A and B (also for the HEDS-5540 and HEDM-5540). Comparators receive the signals and produce the digital outputs for channels A and B. Due to this integration technique, the digital output for channel A is in quadrature with that of channel B and is out of phase.

In the HEDS-5540 and HEDM-5540, the output of the index pulse (I and I-bar) is sent to the processing circuitry.

Theory of Operation

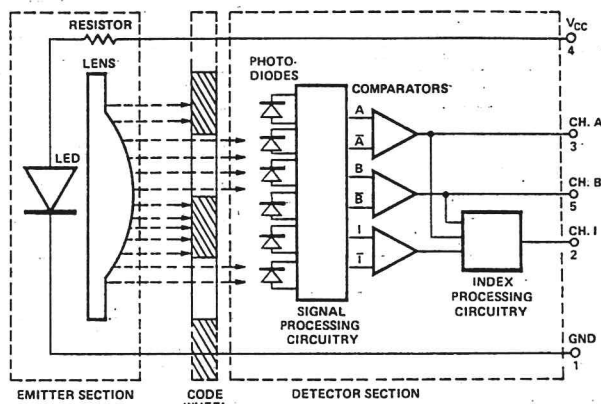
The HEDS-5500, 5540, 5600, 5640, and HEDM-5500, 5600 translate the rotary motion of a shaft into either a two- or a three-channel digital output.

As seen in the block diagram, these encoders contain a single Light Emitting Diode (LED) as its light source. The light is collimated into a parallel beam by means of a single polycarbonate lens located directly over the LED. Opposite the emitter is the integrated detector circuit. This IC consists of multiple sets of photodetectors and the signal processing circuitry necessary to produce the digital waveforms.

The codewheel rotates between the emitter and detector, causing the light beam to be interrupted by the pattern of spaces and bars on the codewheel. The photodiodes which detect these interruptions are arranged in a pattern that corresponds to the radius and design of the codewheel. These detectors are also spaced such that a light period on one pair of detectors corresponds to a dark period on the adjacent pair of detectors. The photodiode outputs are then fed through the signal processing circuitry resulting in A, \bar{A} , B and \bar{B} (also I and \bar{I} in the HEDS-5540 and 5640). Comparators receive these signals and produce the final outputs for channels A and B. Due to this integrated phasing technique, the digital output of channel A is in quadrature with that of channel B (90 degrees out of phase).

In the HEDS-5540 and 5640, the output of the comparator for I and \bar{I} is sent to the index processing circuitry along with

Block Diagram



NOTE: CIRCUITRY FOR CH. I IS ONLY IN HEDS-5540 AND 5640 THREE CHANNEL ENCODERS.

the outputs of channels A and B. The final output of channel I is an index pulse P_0 which is generated once for each full rotation of the codewheel. This output P_0 is a one state width (nominally 90 electrical degrees), high true index pulse which is coincident with the low states of channels A and B.

Definitions

Count (N): The number of bar and window pairs or counts per revolution (CPR) of the codewheel.

One Cycle (C): 360 electrical degrees ($^\circ$), 1 bar and window pair.

One Shaft Rotation: 360 mechanical degrees, N cycles.

Position Error ($\Delta\theta$): The normalized angular difference between the actual shaft position and the position indicated by the encoder cycle count.

Cycle Error (ΔC): An indication of cycle uniformity. The difference between an observed shaft angle which gives rise to

one electrical cycle, and the nominal angular increment of $1/N$ of a revolution.

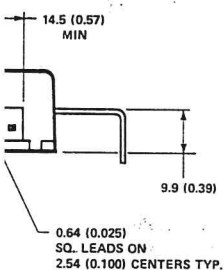
Pulse Width (P): The number of electrical degrees that an output is high during 1 cycle. This value is nominally 180° or $1/2$ cycle.

Pulse Width Error (ΔP): The deviation, in electrical degrees, of the pulse width from its ideal value of 180° .

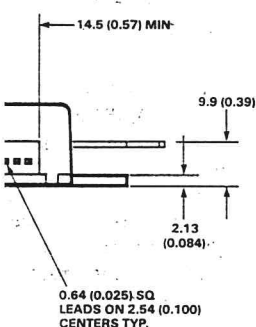
State Width (S): The number of electrical degrees between a transition in the output of channel A and the neighboring transition in the output of channel B. There are 4 states per cycle, each nominally 90° .

State Width Error (ΔS): The deviation, in electrical degrees, of each state width from its ideal value of 90° .

Phase (ϕ): The number of electrical degrees between the center of the high state of channel A and the center of the high state of channel B. This value is nominally 90° for quadrature output.



output.



REMOVING HEX WRENCH. (INCHES).

output.

Absolute Maximum Ratings

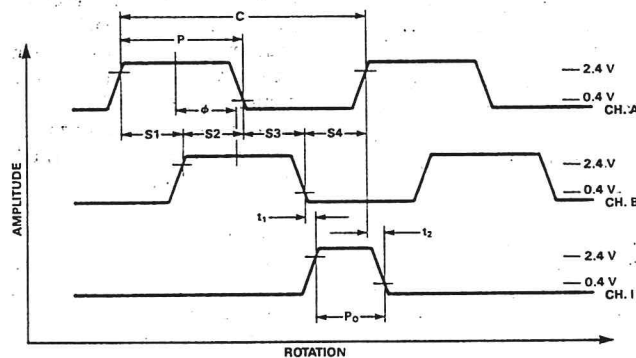
Parameter	HEDS-55XX/56XX	HEDM-550X/560X
Storage Temperature, T_S	-40°C to 100°C	-40°C to +70°C
Operating Temperature, T_A	-40°C to 100°C	-40°C to +70°C
Supply Voltage, V_{CC}	-0.5 V to 7 V	-0.5 V to 7 V
Output Voltage, V_O	-0.5 V to V_{CC}	-0.5 V to V_{CC}
Output Current per Channel, I_{OUT}	-1.0 mA to 5 mA	-1.0 mA to 5 mA
Vibration	20 g, 5 to 1000 Hz	20 g, 5 to 1000 Hz
Shaft Axial Play	± 0.25 mm (± 0.010 in.)	± 0.175 mm (± 0.007 in.)
Shaft Eccentricity Plus Radial Play	0.1 mm (0.004 in.) TIR	0.04 mm (0.0015 in.) TIR
Velocity	30,000 RPM	30,000 RPM
Acceleration	250,000 rad/sec ²	250,000 rad/sec ²

Phase Error ($\Delta\phi$): The deviation of the phase from its ideal value of 90°e.

Direction of Rotation: When the codewheel rotates in the counterclockwise direction (as viewed from the encoder end of the motor), channel A will lead channel B. If the codewheel rotates in the clockwise direction, channel B will lead channel A.

Index Pulse Width (P_O): The number of electrical degrees that an index output is high during one full shaft rotation. This value is nominally 90°e or 1/4 cycle.

Output Waveforms



Recommended Op

Parameter
Temperature HEDS Ser
Temperature HEDM Ser
Supply Voltage
Load Capacitance
Count Frequency
Shaft Perpendicularity Plus Axial Play (HEDS)
Shaft Eccentricity Plus Radial Play (HEDS Ser)
Shaft Perpendicularity Plus Axial Play (HEDM)
Shaft Eccentricity Plus Radial Play (HEDM Ser)

Note: The module performance required for HEDS-5540 and

Encoding Character

Part No.	Part No.
HEDS-5500 HEDS-5600 (Two Channel)	Pu Lo Ph Po Cy
HEDM-5500 HEDM-5600	Pu Lo Ph Po Cy
HEDS-5540 HEDS-5640 (Three Channel)	Pu Lo Ph Po Cy In C C C C

Note: See Mechanical Characteristics. *Typical values specified.

Recommended Operating Conditions

Parameter	Symbol	Min.	Typ.	Max.	Units	Notes
Temperature HEDS Series	T _A	-40		100	°C	
Temperature HEDM Series	T _A	-40		70	°C	non-condensing atmosphere
Supply Voltage	V _{CC}	4.5	5.0	5.5	Volts	Ripple < 100 mV _{P-P}
Load Capacitance	C _L			100	pF	2.7 kΩ pull-up
Count Frequency	f			100	kHz	Velocity (rpm) x N/60
Shaft Perpendicularity Plus Axial Play (HEDS Series)				±0.25 (±0.010)	mm (in.)	6.9 mm (0.27 in.) from mounting surface
Shaft Eccentricity Plus Radial Play (HEDS Series)				0.04 (0.0015)	mm (in.) TIR	6.9 mm (0.27 in.) from mounting surface
Shaft Perpendicularity Plus Axial Play (HEDM Series)				±0.175 (±0.007)	mm (in.)	6.9 mm (0.27 in.) from mounting surface
Shaft Eccentricity Plus Radial Play (HEDM Series)				0.04 (0.0015)	mm (in.) TIR	6.9 mm (0.27 in.) from mounting surface

Note: The module performance is guaranteed to 100 kHz but can operate at higher frequencies. 2.7 kΩ pull-up resistors required for HEDS-5540 and 5640.

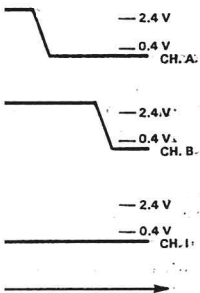
Encoding Characteristics

Encoding Characteristics over Recommended Operating Range and Recommended Mounting Tolerances unless otherwise specified. Values are for the worst error over the full rotation.

Part No.	Description	Sym.	Min.	Typ.*	Max.	Units	
HEDS-5500	Pulse Width Error	ΔP		7	45	°e	
HEDS-5600	Logic State Width Error	ΔS		5	45	°e	
(Two Channel)	Phase Error	Δφ		2	20	°e	
	Position Error	ΔΘ		10	40	min. of arc	
	Cycle Error	ΔC		3	5.5	°e	
HEDM-5500	Pulse Width Error	ΔP		10	45	°e	
HEDM-5600	Logic State Width Error	ΔS		10	45	°e	
	Phase Error	Δφ		2	15	°e	
	Position Error	ΔΘ		10	40	min. of arc	
	Cycle Error	ΔC		3	7.5	°e	
HEDS-5540	Pulse Width Error	ΔP		5	35	°e	
HEDS-5640	Logic State Width Error	ΔS		5	35	°e	
(Three Channel)	Phase Error	Δφ		2	15	°e	
	Position Error	ΔΘ		10	40	min. of arc	
	Cycle Error	ΔC		3	5.5	°e	
	Index Pulse Width	P ₀	55	90	125	°e	
	CH. I rise after CH. A or CH. B fall	t ₁	-25°C to +100°C	10	100	250	ns
		t ₁	-40°C to +100°C	-300	100	250	ns
	CH. I fall after CH. B or CH. A rise	t ₂	-25°C to +100°C	70	150	300	ns
		t ₂	-40°C to +100°C	70	150	1000	ns

Note: See Mechanical Characteristics for mounting tolerances.
*Typical values specified at V_{CC} = 5.0 V and 25°C.

EDM-550X/560X
C to +70°C
C to +70°C
V to 7 V
V to V _{CC}
mA to 5 mA
5 to 1000 Hz
75 mm (±0.007 in.)
mm (0.0015 in.) TIR.
00 RPM
000 rad/sec ²



Electrical Characteristics

Electrical Characteristics over Recommended Operating Range.

Part No.	Parameter	Sym.	Min.	Typ.*	Max.	Units	Notes
HEDS-5500 HEDS-5600	Supply Current	I_{CC}		17	40	mA	
	High Level Output Voltage	V_{OH}	2.4			V	$I_{OH} = -40 \mu\text{A max.}$ $I_{OL} = 3.2 \text{ mA}$
	Low Level Output Voltage	V_{OL}			0.4	V	
	Rise Time	t_r		200		ns	$C_L = 25 \text{ pF}$ $R_L = 11 \text{ k}\Omega$ pull-up
Fall Time	t_f		50		ns		
HEDS-5540 HEDS-5640 HEDM-5500 HEDM-5600	Supply Current	I_{CC}	30	57	85	mA	
	High Level Output Voltage	V_{OH}	2.4			V	$I_{OH} = -200 \mu\text{A max.}$ $I_{OL} = 3.86 \text{ mA}$
	Low Level Output Voltage	V_{OL}			0.4	V	
	Rise Time	t_r		180		ns	$C_L = 25 \text{ pF}$ $R_L = 2.7 \text{ k}\Omega$ pull-up
Fall Time	t_f		40		ns		
HEDM-5500 HEDM-5600	Supply Current	I_{CC}	30	57	85	mA	
	High Level Output Voltage	V_{OH}	2.4			V	$I_{OH} = -40 \mu\text{A max.}$ $I_{OL} = 3.86 \text{ mA}$
	Low Level Output Voltage	V_{OL}			0.4	V	
	Rise Time	t_r		180		ns	$C_L = 25 \text{ pF}$ $R_L = 3.2 \text{ k}\Omega$ pull-up
Fall Time	t_f		40		ns		

*Typical values specified at $V_{CC} = 5.0 \text{ V}$ and 25°C .

Mechanical Chara

Parameter
Codewheel Fits These Standard Shaft Diamet
Moment of Inertia
Required Shaft Length
Bolt Circle ⁽³⁾
Mounting Screw Size ⁽⁴⁾
Encoder Base Plate Thickness
Hub Set Screw

Notes:

1. These are tolerances requir
2. The HEDS-55X5 and 56X5, motor shafts. See Ordering In
3. The HEDS-5540 and 5640 shown in "Encoder Mounting
4. The recommended mountir mounting screw torque for 3

Electrical Interfa

To insure reliable encoc performance, the HEDS and 5640 three channel encoders require 2.7 k Ω pull-up resistors on out 2, 3, and 5 (Channels I, B) as shown in Figure 1 pull-up resistors should

Mechanical Characteristics

Parameter	Symbol	Dimension	Tolerance ^[1]	Units
Codewheel Fits These Standard Shaft Diameters		2 3 4 5 6 8	+0.000 -0.015	mm
		5/32 1/8 3/16 1/4	+0.0000 -0.0007	in
Moment of Inertia	J	0.6 (8.0 x 10 ⁻⁶)		g-cm ² (oz-in-s ²)
Required Shaft Length ^[2]		14.0 (0.55)	±0.5 (±0.02)	mm (in.)
Bolt Circle ^[3]	2 screw mounting	19.05 (0.750)	±0.13 (±0.005)	mm (in.)
	3 screw mounting	20.90 (0.823)	±0.13 (±0.005)	mm (in.)
	external mounting ears	46.0 (1.811)	±0.13 (±0.005)	mm (in.)
Mounting Screw Size ^[4]	2 screw mounting	M 2.5 or (2-56)		mm (in.)
	3 screw mounting	M 1.6 or (0-80)		mm (in.)
	external mounting ears	M 2.5 or (2-56)		mm (in.)
Encoder Base Plate Thickness		0.33 (0.130)		mm (in.)
Hub Set Screw		(2-56)		(in.)

Notes:

- These are tolerances required of the user.
- The HEDS-55X5 and 56X5, HEDM-5505, 5605 provide an 8.9-mm (0.35 inch) diameter hole through the housing for longer motor shafts. See Ordering Information.
- The HEDS-5540 and 5640 must be aligned using the aligning pins as specified in Figure 3, or using the alignment tool as shown in "Encoder Mounting and Assembly". See also "Mounting Considerations."
- The recommended mounting screw torque for 2 screw and external ear mounting is 1.0 kg-cm (0.88 in-lbs). The recommended mounting screw torque for 3 screw mounting is 0.50 kg-cm (0.43 in-lbs).

Electrical Interface

To insure reliable encoding performance, the HEDS-5540 and 5640 three channel encoders require 2.7 kΩ (±10%) pull-up resistors on output pins 2, 3, and 5 (Channels I, A, and B) as shown in Figure 1. These pull-up resistors should be

located as close to the encoder as possible (within 4 feet). Each of the three encoder outputs can drive a single TTL load in this configuration.

The HEDS-5500, 5600, and HEDM-5500, 5600 two channel encoders do not normally

require pull-up resistors. However, 3.2 kΩ pull-up resistors on output pins 3 and 5 (Channels A and B) are recommended to improve rise times, especially when operating above 100 kHz frequencies.

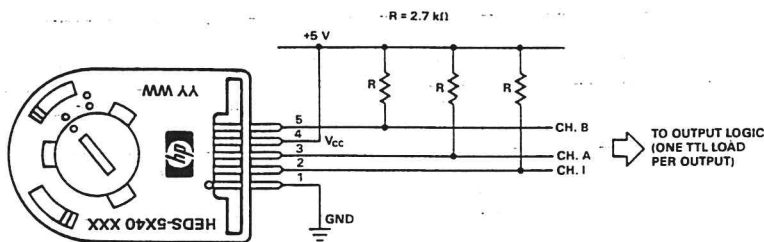


Figure 1. Pull-up Resistors on HEDS-5X40 Encoder Outputs.

Mounting Considerations

The HEDS-5540 and 5640 three channel encoders and the HEDM Series high resolution encoders must be aligned using the aligning pins as specified in Figure 3, or using the HEDS-8910 Alignment Tool as shown in Encoder Mounting and Assembly.

The use of aligning pins or alignment tool is recommended but not required to mount the

HEDS-5500 and 5600. If these two channel encoders are attached to a motor with the screw sizes and mounting tolerances specified in the mechanical characteristics section without any additional mounting bosses, the encoder output errors will be within the maximums specified in the encoding characteristics section.

The HEDS-5500 and 5540 can be mounted to a motor using either the two screw or three

screw mounting option as shown in Figure 2. The optional aligning pins shown in Figure 3 can be used with either mounting option.

The HEDS-5600, 5640, and HEDM-5600 have external mounting ears which may be used for mounting to larger motor base plates. Figure 4 shows the necessary mounting holes with optional aligning pins and motor boss.

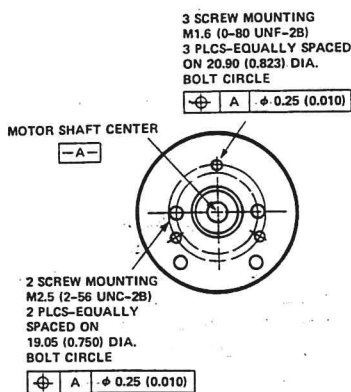


Figure 2. Mounting Holes.

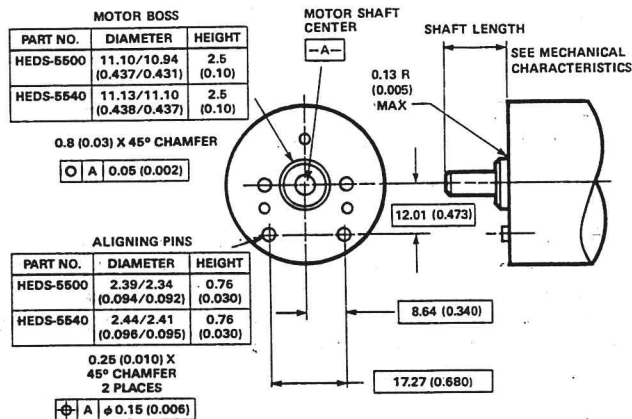
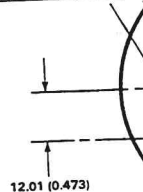


Figure 3. Optional Mounting Aids.

M2.5 (2-56 UNC-2B)
2 PLCS EQUALLY
SPACED ON
45.0 (1.811) DIA
BOLT CIRCLE
A ϕ 0.25 (0.010)



8.64
17.27
DIMENSIONS IN MM (INCHES)

Figure 4. Mounting with External Mounting Ears.

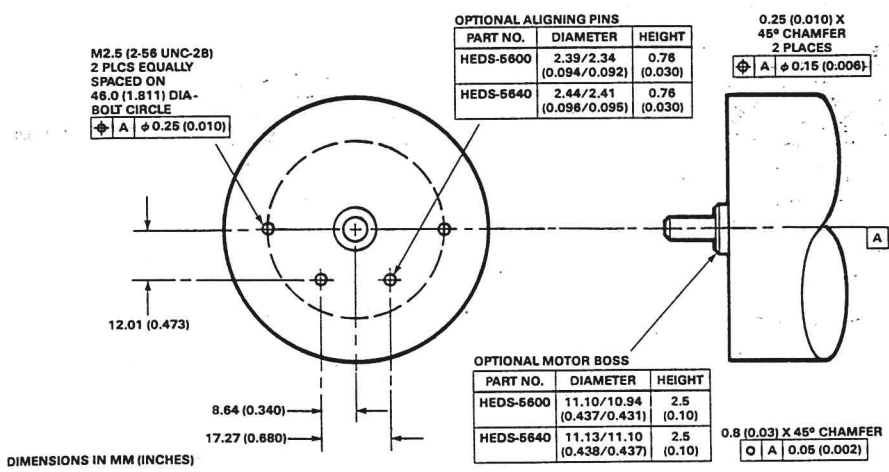
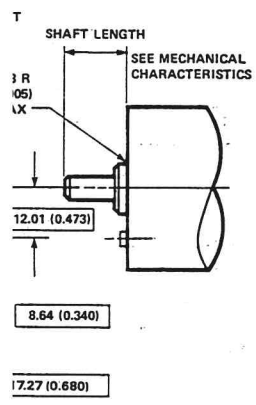


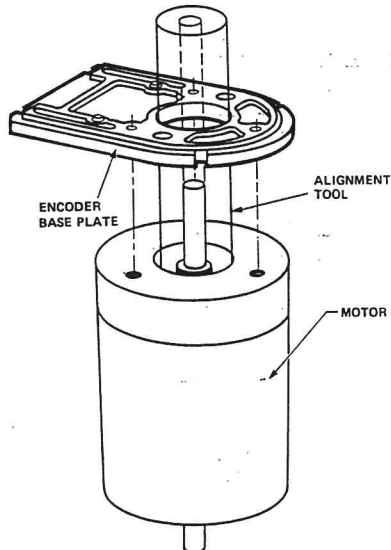
Figure 4. Mounting with External Ears.

mounting option as shown in Figure 2. The optional aligning pins shown in Figure 3 may be used with either mounting option.

HEDS-5600, 5640, and 5660 have external mounting ears which may be used for mounting to larger base plates. Figure 4 shows the necessary mounting dimensions with optional aligning pins and optional motor boss.

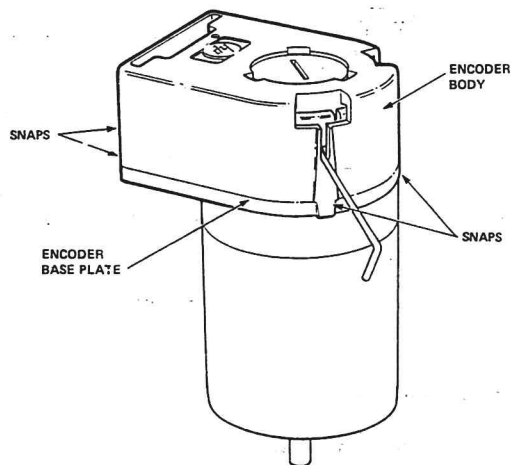


Encoder Mounting and Assembly

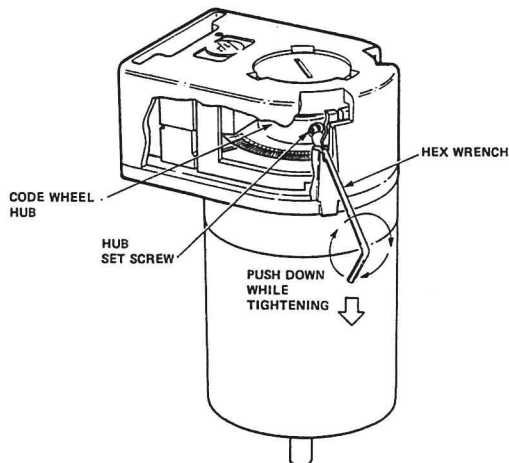


1. For HEDS-5500 and 5600: Mount encoder base plate onto motor. Tighten screws. Go on to step 2.

1a. For HEDS-5540, 5640 and HEDM-5500, 5600: Slip alignment tool onto motor shaft. With alignment tool in place, mount encoder baseplate onto motor as shown above. Tighten screws. Remove alignment tool.



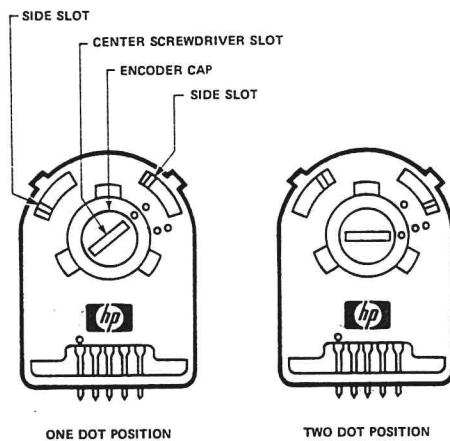
2. Snap encoder body onto base plate locking all 4 snaps.



3a. Push the hex wrench into the body of the encoder to ensure that it is properly seated into the code wheel hub set screws. Then apply a downward force on the end of the hex wrench. This sets the code wheel gap by levering the code wheel hub to its upper position.

3b. While continuing to apply a downward force, rotate the hex wrench in the clockwise direction until the hub set screw is tight against the motor shaft. The hub set screw attaches the code wheel to the motor's shaft.

3c. Remove the hex wrench by pulling it straight out of the encoder body.



4. Use the center screwdriver slot, or either of the two side slots, to rotate the encoder cap dot clockwise from the one dot position to the two dot position. Do not rotate the encoder cap counterclockwise beyond the one dot position.

The encoder is ready for use!

Connectors

Manufacturer
AMP
Dupont/Berg
HP (designed to mecha HEDS-55XX, HED
Molex

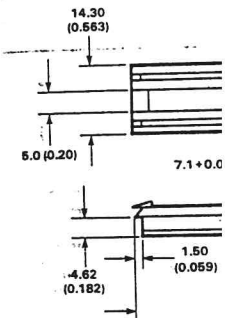


Figure 5. HEDS-8902 a

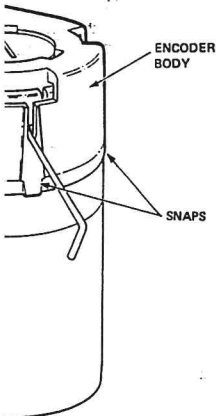
Typical Interfa

HEDS-55XX	CH.
OR	
HEDS-56XX	CH.
OR	
HEDM-5XXX	

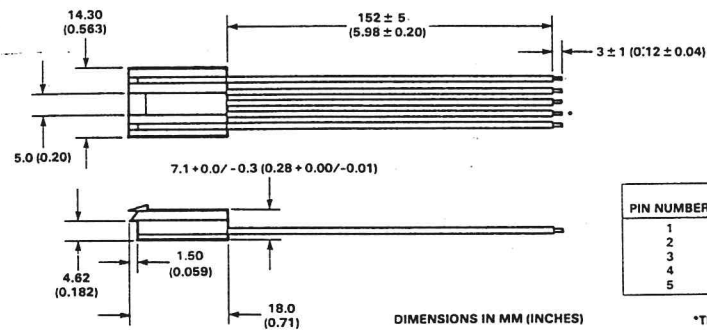
HEDS-55XX	CH.
OR	
HEDS-56XX	CH.
OR	
HEDM-5XXX	

Connectors

Manufacturer	Part Number
AMP	103686-4 640442-5
Dupont/Berg	65039-032 with 4825X-000 term.
HP (designed to mechanically lock into the HEDS-55XX, HEDM-5XXX Series)	HEDS-8902 (2 ch.) with 4-wire leads
	HEDS-8903 (3 ch.) with 5-wire leads
Molex	2695 series with 2759 series term.



se plate locking all 4



PIN NUMBER	PARAMETER	HEDS-8902 COLORS	HEDS-8903 COLORS
1	GROUND	BLACK	BLACK
2	CH. I	N/A*	BLUE
3	CH. A	WHITE	WHITE
4	V _{cc}	RED	RED
5	CH. B	BROWN	BROWN

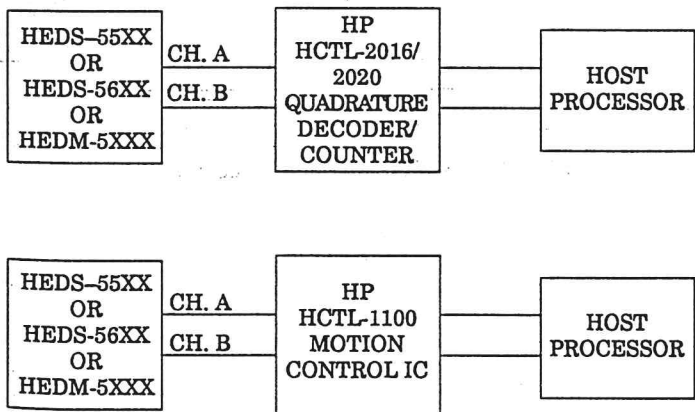
*THIS WIRE IS NOT ON HEDS-8902.

Figure 5. HEDS-8902 and 8903 Connectors.

SLOT

IT

Typical Interfaces

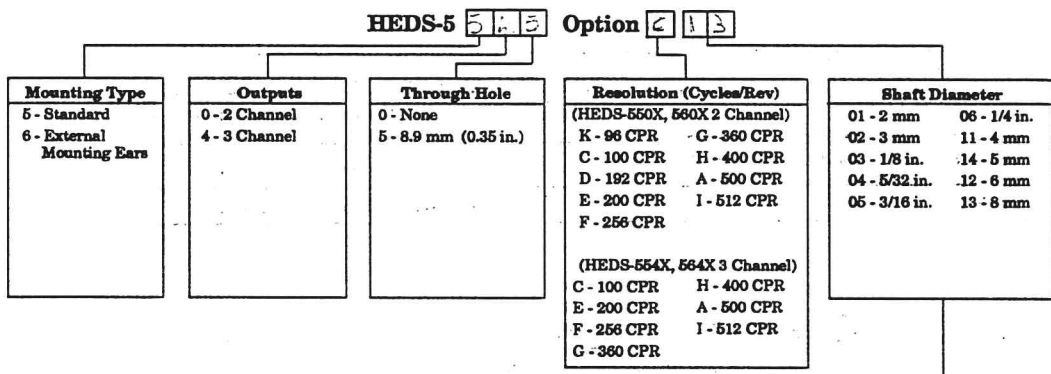


TWO DOT POSITION
slot, or either of the two
ler cap dot clockwise from
o dot position. Do not
erclockwise beyond the

new
Encoder I
Technical I

Ordering Information

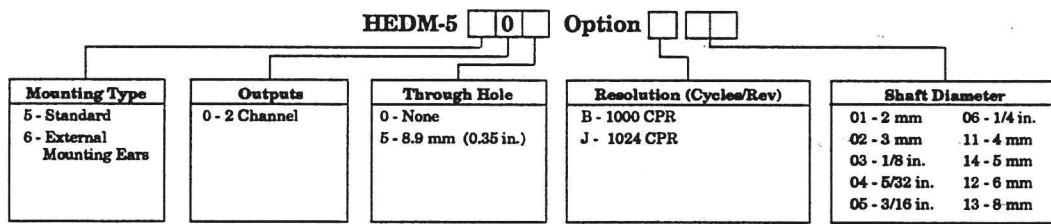
Encoders with Metal Codewheels



HEDS-8910 0 Alignment Tool

(Included with each order of HEDS-554X/564X three channel encoders)

Encoders with Film Codewheels



HEDS-8910 0 Alignment Tool

(Included with each order of HEDM-550X/560X three channel encoders)

Features

- Available on Both Modules (HEDS-5 Series) and Enclosures (HEDS-8 Series)
- Complementary Outputs
- High Flex Twisted Pair Cable with Connector
- Industry Standard Line Driver IC
- Single 5 V Supply
- Onboard Bypass

Description

Line Driver options are available on the HEDS-55XX series and the HEDS-89000/9100/9200/9040 series encoders. The

Device Characteristic

Option
Termination
Electrical Outputs
Line Driver Components
Operating Temperature Range
Storage Temperature
ESD WARNING: STATIC DISCHARGE

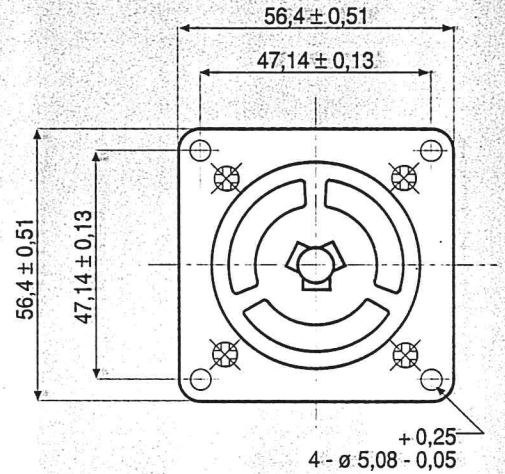
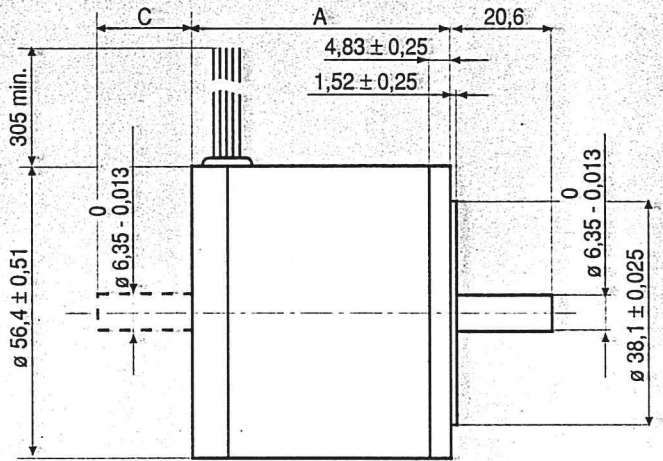
(Installation Instructions)





SERIE 103 - 770

STEPPING MOTOR
Step-Syn

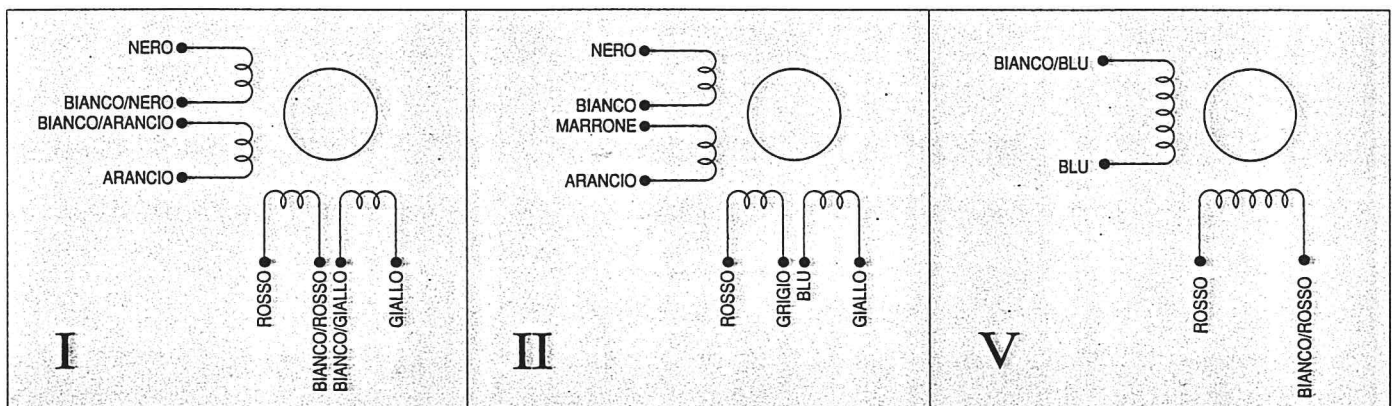


MODELLO	A	C
103 - 770 - 6	50,8	
103 - 770 - 61	50,8	19,05
103 - G770 - 2241	50,8	
103 - G770 - 2211	50,8	19,05
103 - 770 - 1640	50,8	

CARATTERISTICHE

MODELLO		103 - 770 - 6 (103 - 770 - 61)	103 - G770 - 2241 (103 - G770 - 2211)	103 - 770 - 1640
ANGOLO DI PASSO - TOLLERANZA		1,8° ± 0,09°	1,8° ± 0,09°	1,8° ± 0,09°
CORRENTE NOMINALE BIPOLARE	(Amp)	1,41	2,82	1,41
CORRENTE NOMINALE UNIPOLARE	(Amp)	1,0	2,0	
RESISTENZA DI FASE A 25°	(OHM)	5,1	1,4	2,6
INDUTTANZA DI FASE	(mH)	9,0	2,2	9,0
COPPIA DI TENUTA BIPOLARE	(Ncm)	62	54	62
COPPIA DI TENUTA UNIPOLARE	(Ncm)	49	43	
MOMENTO D'INERZIA ROTORE	(Kgm ² x 10 ⁻⁷)	105	105	105
ACCELERAZIONE TEORICA	(rad x sec. ⁻²)	59000	52000	59000
FORZA CONTRO ELETTRO MOTRICE	(V/Krpm)	37	17	33
PESO	(Kg)	0,54	0,54	0,54
CODICE TERMINALI		I	I (II)	V

Le sigle e le caratteristiche fra parentesi si riferiscono ai modelli bialbero.



LOW-SPEED SYNCHRONOUS MOTORS

Excellent starting, stopping and reverse action. Ideal for applications requiring fixed feeding, stopping at fixed positions, program timing and so on.

FEATURES

- Superb starting, stopping and reverse action.
- Short cycle ON/OFF switching simple since current remains the same during running, starting and reverse operation.
- Symmetrical windings for easy forward/reverse operation.
- Rate of revolution proportionate to frequency of power source (72rpm. at 60Hz).
- Noise levels low since low speeds are possible with just the motor.
- Extremely low speeds and high torque possible without reduction gears.
- Permanently magnetized multipolar rotor for good holding characteristics, even without excitation.
- High holding torque possible with the application of DC voltage.
- Long life and high reliability thanks to the elimination of parts subject to mechanical wear.
- Output torque can be increased by raising applied voltage.

SPECIFICATIONS

1) MOTORS

Continuous ratings

Motor type		Output power		Hz	Volts	Rated Load				Residual Torque oz-in (N-cm)	Rotor Inertia oz-in ² (g-cm ²)	Capacitor		Resistor		Dimensions NO./Wiring Diagrams NO.
Single Shaft	Double Shaft	HP	Watts			Amps	Watts	Rpm	Torque oz-in (N-cm)			Mfd.	Vac.	Ohm	Watts	
2CSM-101	2CSM-102	1/414	1.8	60	115	0.14	13	72	33.3 (23.5)	1.39 (0.98)	0.87 (160)	1.2	250			①/①
4CSM-101	4CSM-102	1/169	4.4	60	115	0.2	13	72	83.3 (58.8)	5.56 (3.93)	3.06 (560)	1.5	250	400	30	②/②
4CSM-111	4CSM-112	1/113	6.6	60	115	0.3	25	72	125 (88.3)	7.64 (5.39)	6.01 (1100)	2.5	250	400	30	③/③

*Pinion shaft type

$\rightarrow 0.16 \cdot 10^{-4} \text{ kg} \cdot \text{m}^2$

2) GEARMOTOR TORQUE TABLE (lb-in)

Boxes () are to be replaced with the desired gear ratio, which thus becomes part of the code for the gearmotor.

RPM	24	20	14.4	12	9.6	8	5.76	4.8	4	2.88	2.4	2	1.44	1.2	0.96	0.8	0.72	0.6	0.48	0.4	Dimensions NO./Wiring Diagrams NO.
	3	3.6	5	6	7.5	9	12.5	15	18	25	30	36	50	60	75	90	100	120	150	180	
2CSMGK-101/2GK <input type="checkbox"/> KA 2CSMGK-101/2GK <input type="checkbox"/> A	4.0	4.8	6.7	8.1	10	12	17	20	22	22	22	22	22	22	22	22	22	22	22	22	④/④
4CSMGK-101/4GK <input type="checkbox"/> KA 4CSMGK-101/4GK <input type="checkbox"/> A	10	12	17	20	25	30	42	50	61	69	69	69	69	69	69	69	69	69	69	69	⑤/⑤

A color background indicates that the output shaft of the gearmotor rotates in the same direction as the output shaft of the motor. A white background indicates rotation in the opposite direction.

The letter KA (A) is used to identify ball bearing (sleeve bearing) type gearheads.

GENERAL SPECIFICATIONS

Insulation Resistance

100M ohms or more under normal ambient temperature and humidity when the megger reading between the windings and frame is DC500V.

Dielectric Strength

Under normal ambient temperature and humidity, sufficient to withstand 1.5KV at 60Hz applied between the windings and the frame for one minute following a period of continuous operation.

Temperature Rise

55°C (131°F) or less as measured by thermometer method after the temperature of the motor housing has stabilized under normal operation at the rated voltage, frequency and load.

Working Temperature Range

-10°C to +40°C (14°F to 104°F)

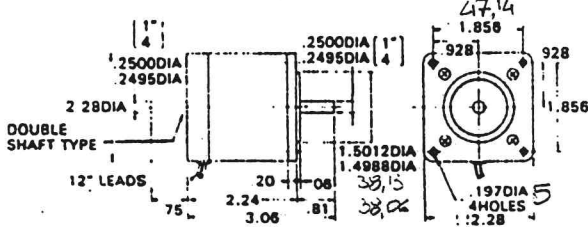
Rappresentante esclusivo per l'Italia:

MCA ESCLUSIVO PER L'ITALIA
 MOTORI CONTROLLI APPLICAZIONI
 20016 Pero (MI) - Via F. Turati, 21 - Tel. 02/33910450 - Telex 350211 MCA I
 Telefax 02/3390858

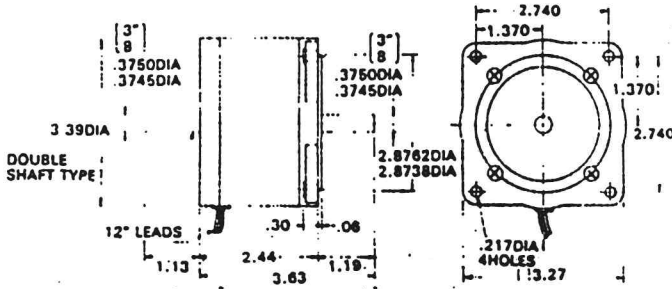
DIMENSIONS

1) MOTORS (scale 1:4, unit = inch)

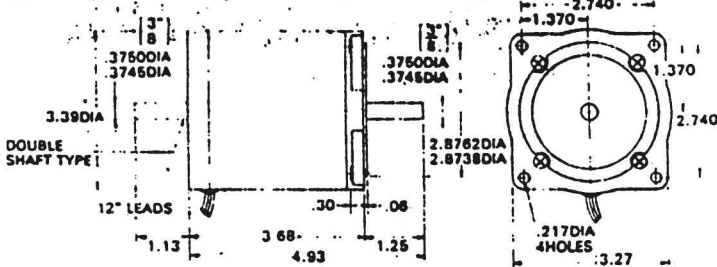
① 2CSM-101, 102 Weight: 1.43 lbs (0.65 Kg)



② 4CSM-101, 102 Weight: 3.31 lbs (1.5 Kg)

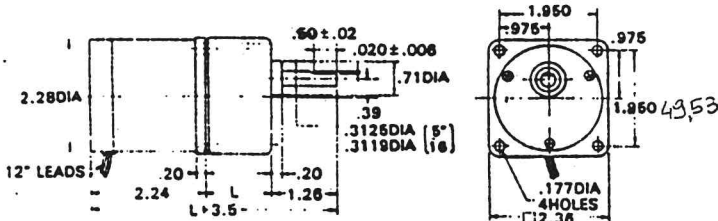


③ 4CSM-111, 112 Weight: 5.51 lbs (2.5 Kg)

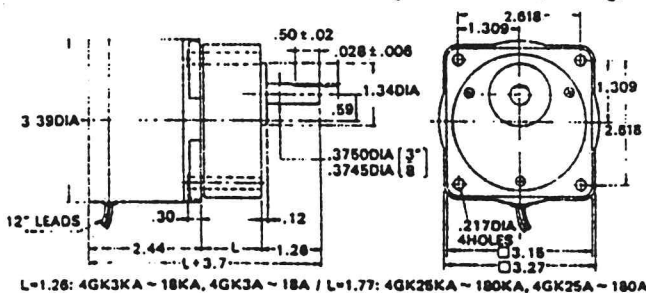


2) GEAR MOTORS (scale 1:4, unit = inch)

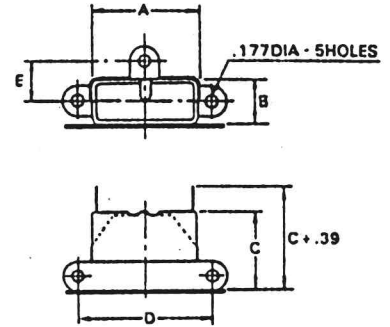
④ 2CSMGK-101/2GK□KA Weight: 2.31 lbs (1.05 Kg) 2CSMGK-101/2GK□A Weight: 2.20 lbs (1.0 Kg)



⑤ 4CSMGK-101/4GK□KA Weight: 4.74 lbs (2.15 Kg) 4CSMGK-101/4GK□A Weight: 4.63 lbs (2.1 Kg)



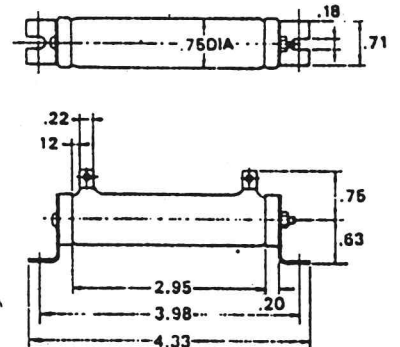
3) CAPACITOR (unit = inch)



Motor type	Capacitor Part Number	Mfd.	Vac.	A	B	C	D	E
2CSM-101, 102	CH12	1.2	250	1.32	.49	.94	1.71	.4
2CSMGK-101	CH12	1.2	250	1.32	.49	.94	1.71	.4
4CSM-101, 102	CH15	1.5	250	1.32	.49	.94	1.71	.4
4CSMGK-101	CH15	1.5	250	1.32	.49	.94	1.71	.4
4CSM-111, 112	CH25	2.5	250	1.42	.55	1.04	1.89	.4

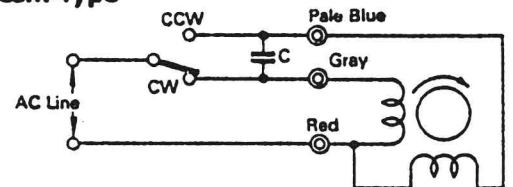
4) RESISTOR (scale 1:3, unit = inch)

400 ohm, 30 watts

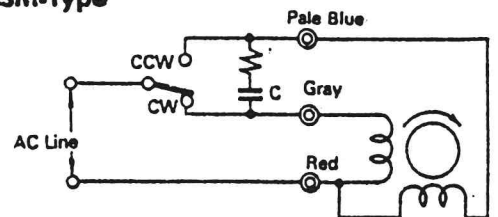


WIRING DIAGRAMS

① 2CSM-type



② 4CSM-type



The direction of motor is as viewed from the front shaft end.

TECHNICAL INFORMATION

1) Single-Phase Operation

The connections for operation using a single-phase power supply are shown in Fig-1. With 2CSM types, the connections are the same as for Oriental reversible motors. With 4CSM types, it will be necessary to connect a resistor (R) in series with the capacitor. Since the windings of the main and auxiliary windings are symmetrical, connecting this motor as shown in Fig-1 makes forward and reverse operation possible. Note that operating the motor with capacitors (C) or resistors (R) with values other than those stated in the catalog will cause variations in vibration, temperature rise, and other characteristics.

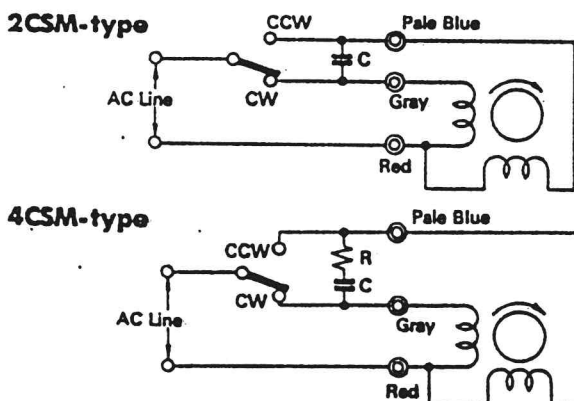


Fig-1. The direction of motor is as viewed from the front shaft end.

2) Speed

The structure of the low-speed synchronous motor is as shown in Fig-2. 48 teeth are evenly spaced around the inner circumference of the stator. The rotor is magnetized along the direction of the shaft and 50 teeth are evenly spaced around its outer circumference.

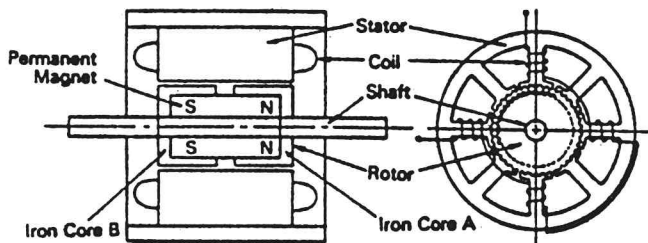


Fig-2. Structure of the stator and rotor of an Oriental Motor Low-Speed Synchronous Motor.

When alternating current is applied to the stator winding, a rotating magnetic field is generated. Magnetic attraction develops between the internal teeth of the stator and the external teeth of the rotor, causing the rotor to turn. Accordingly, the speed of rotation (rpm) of the rotor can be expressed as follows:

$$N = \frac{120}{P} f \times \frac{2}{50}$$

f: Power source frequency (Hz)
P: Number of motor poles
N = Speed (r.p.m.)

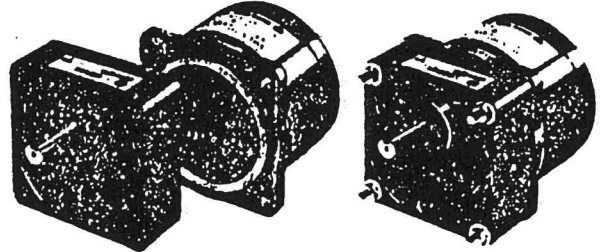
Since P = 4, N = 1.2f

To change the rate of revolution, it is necessary to alter the frequency of the power source. If the frequency is altered, it will also be necessary to change the applied voltage, the capacitor and the resistance value.

Note: A geared type is available for applications requiring speed reduction.

3) Effect of Gearing

By attaching a gearhead to a low-speed synchronous motor, it is possible to obtain lower speeds and higher torque.



For example, if a 6:1 gearhead is attached to a 2CSMGK-101 low-speed synchronous motor (72rpm, 33.3 oz-in), the rate of revolution is reduced to one-sixth, or 12rpm, and the output torque is increased 6 times to 199.8 oz-in. Another advantage of using a gearhead is that the inertial load can be increased in proportion to the square of the gear ratio. The permissible inertial load for the 2CSMGK-101 is 4.10 oz-in² (see Table 4). When a 6:1 gearhead is attached, this increases by a factor of 36 to 147.6 oz-in.

* When a 6:1 gearhead is attached to the 2CSMGK-101 (72rpm, 33.3 oz-in), the rate of revolution is reduced to one-sixth, or 12rpm, and the output torque is increased 6 times to 199.8 oz-in. However, these figures are theoretical and in reality we cannot guarantee that output torque will increase by a factor of 6 because of the gear loss factor. Refer to the Gearmotor Torque Table on Page 1.

4) Noise

Since the motor shaft rotates at a much lower rate than in the case of conventional motors, noise resulting from motor rotation is virtually imperceptible. Even with a gear head attached, the noise level is much lower than with an ordinary geared motor. Also, the gearhead is subjected to lower impact loads, thereby lengthening gearhead life.

Table-1 compares the noise level of an Oriental induction motor fitted with a gearhead with a similarly equipped low-speed synchronous motor.

Model Motor/gearhead	Speed (r.p.m.)	Noise Level (dB. A)
2CSMGK-101/2GK30KA	2.4	24 ~ 39
2IK6GK-AA/2GK30KA	60	44 ~ 58
4CSMGK-101/4GK30KA	2.4	29 ~ 41
4IK25GK-AA/4GK30KA	60	50 ~ 62

(5.91 inch from motor side-A range)

Table-1: Noise levels of motors with gearheads attached.

5) Starting and Stopping Characteristics

(1) Starting Time

Low-speed synchronous motors offer superb starting, stopping and instantaneous reversal characteristics. Provided that the motor is operating within permissible inertial load limits, it can be started, stopped or reversed within 1.5 cycles of the applied frequency. The motor will start and reach a steady speed in 5~25 milliseconds. As shown in Fig-3, however, there is a certain amount of variation in the time required for the motor to reach the set speed.

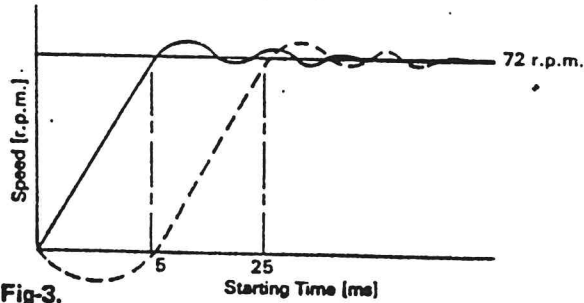


Fig-3.

This is attributable to factors linked with the phase of the power source and the relative positions of the rotor and stator when the current is applied. Occasionally the motor may initially move slightly in the opposite direction, but will then start to rotate in the correct direction. This is a momentary phenomenon and can be disregarded. Even when this type of reverse motion occurs, the motor will start to rotate in the correct direction within 25 milliseconds. One method of reducing these variations is to use a zero cross switch. Other possibilities include the use of special control circuits.

Nevertheless, compared to ordinary reaction synchronous motors, which require approximately 0.1 seconds to start up, the low-speed synchronous motor offers extremely good responsiveness. Moreover, the time required to switch from normal to reverse operation is for all intents and purposes exactly the same as when starting from rest.

(2) Stopping Accuracy

The use of a permanent magnet in the rotor of the low-speed synchronous motor means that the motor can be stopped instantaneously simply by switching off the power supply. Under permissible inertial load conditions, overrun will not exceed 7.2°. Stopping accuracy is within ±3.6°, depending on the relative positions of the rotor and the stator when the stop command is given. Also, after stopping the motor displays the residual characteristics shown in Table-2.

Single Shaft	Double Shaft	Residual Torque oz-in (N-cm)
2CSM-101 2CSMGK-101	2CSM-102	1.39 (0.98)
4CSM-101 4CSMGK-101	4CSM-102	5.56 (3.93)
4CSM-111	4CSM-112	7.64 (5.39)

Table-2: Residual Torque

In applications where larger residual torque is required, quite substantial values can be obtained by applying direct current to the motor winding. Low-speed synchronous motors are constructed with two windings, and each winding is made exactly the same specifications. In general, direct current is applied either to one winding only (refer to the connection diagram in Fig-4) or to both windings in parallel.

If high winding resistance is required, the motor is used with the two windings in series. Refer to the permissible voltage in Figures 5-7 for voltages which can be applied continuously over extended periods. The permissible voltage is determined by the temperature rise of the motor. Regardless of the excitation method used, therefore, the motor input must be kept below a certain level.

The following equation shows the relationships between the applied voltages required for single-phase and two-phase excitation (parallel) to maintain motor input at the same level

$$\frac{V_1^2}{R} = \frac{V_2^2}{R/2} \quad \therefore V_1 = \sqrt{2}V_2$$

V_1 : DC applied voltage for single-phase excitation

V_2 : DC applied voltage for two-phase excitation

R: Resistance per winding

Where the ambient temperature is 40°C (104°F) or higher, and if the motor is to be used in an environment in which heat radiation is poor, care must be taken to ensure that the temperature of the motor shell does not exceed 90°C (194°F).

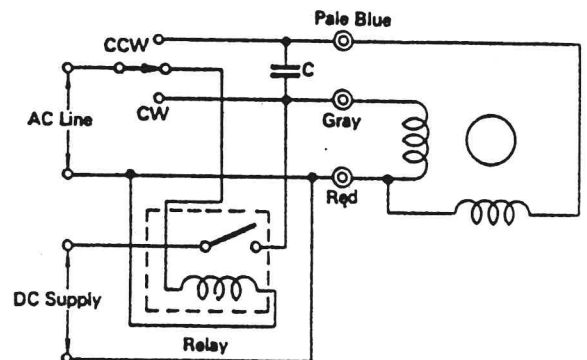


Fig-4: Connections for DC excitation

2CSM-101 (102)

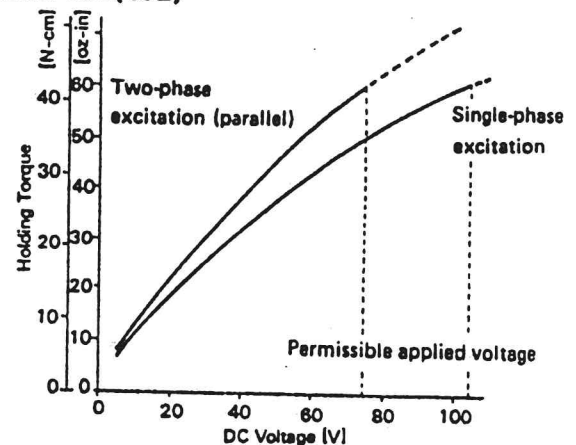


Fig-5: DC voltage/holding torque curves

4CSM-101 (102)

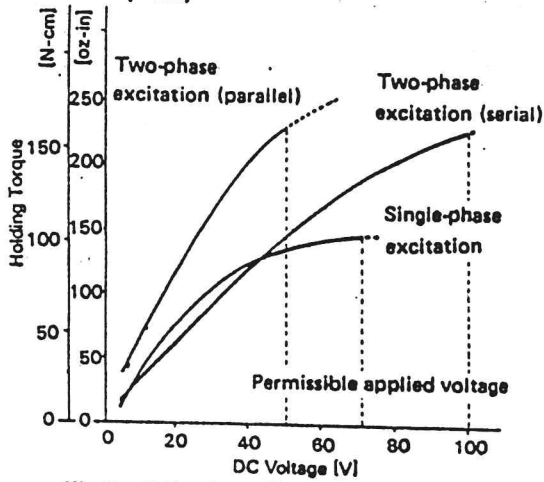


Fig-6: DC voltage/holding torque curves

4CSM-111 (112)

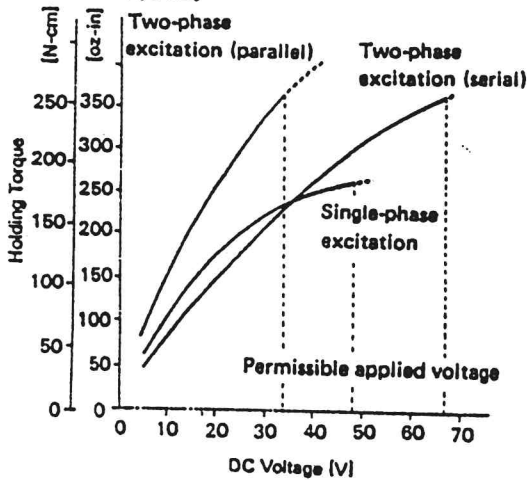


Fig-7: DC voltage/holding torque curves

3) Starting and Running Current

Because of the high rotor impedance of low-speed synchronous motors, there is virtually no difference between starting and running current. This means that short cycle ON-OFF switching and forward-reverse operation can be carried out without any problems occurring. Nor is there any risk of burning when the motor is subjected to continuous stall conditions. Technicians designing machines which incorporate these motors do not have to go to the trouble of devising means of coping with inrush current.

Single Shaft	Double Shaft	Starting current (A)	Running current (A)
2CSM-101 2CSMGK-101	2CSM-102	0.14	0.14
4CSM-101 4CSMGK-101	4CSM-102	0.2	0.2
4CSM-111	4CSM-112	0.3	0.3

Table-3: Rated current

6) Permissible Inertial Loads

The direct coupling of a large inertial load to the motor shaft causes changes in the starting, stopping and reverse characteristics of the motor. The size of the inertial load which can be directly coupled to the motor shaft for normal operation is subject to certain limitations. Permissible inertial load values are as shown in Table-4.

Motor type	Permissible inertial load		Rotor inertia	
	oz-in ²	g-cm ²	oz-in ²	g-cm ²
2CSM-101, 102	6.84	1250	0.87	160
2CSMGK-101	4.10	750	0.87	160
4CSM-101, 102	6.84	1250	3.06	560
4CSMGK-101	6.84	1250	3.06	560
4CSM-111, 112	8.21	1500	6.01	1100

Table-4: Permissible inertial loads

When the motor is to be operated under inertial loads which exceed permissible limits, the use of flexible braking couplings will enable it to work under loads 5~10 times higher than the rated value. One method of applying flexible braking couplings is to link the motor shaft with the load shaft by means of a rubber sleeve as shown in Fig-8. Another alternative is to use a rubber coupling.

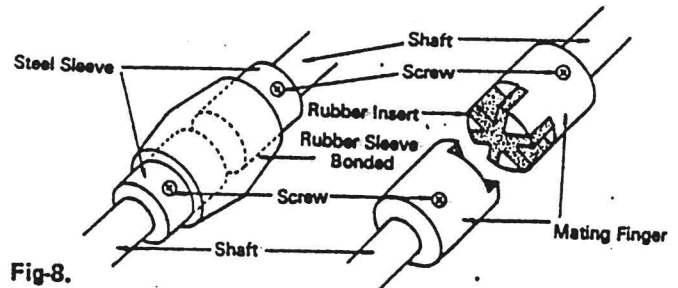


Fig-8.

The use of a timing belt or chain is also effective. These various coupling methods prevent motor vibration from being transmitted to the load and are extremely effective in reducing noise.

7) Torque/Voltage Characteristics

Torque characteristics under differing voltages are as shown in Fig-9. With ordinary motors the torque changes in proportion to the square of the voltage, but with low-speed synchronous motors it is more or less proportionate to the voltage value itself. When the motor is to be used at high voltages, care must be taken to ensure that motor temperature does not exceed the rated level.

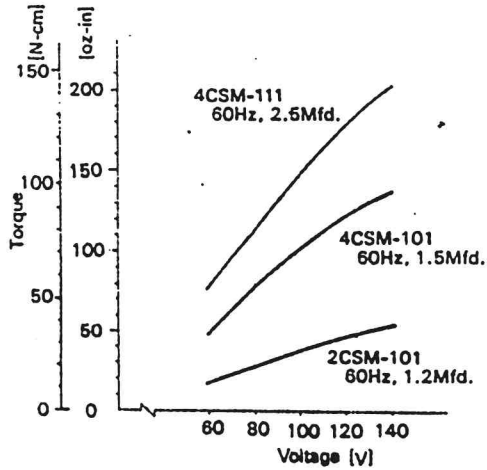
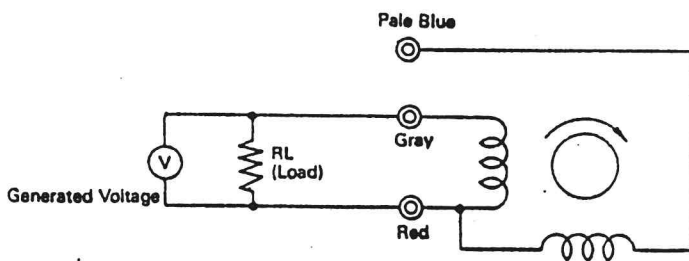


Fig-9: Torque/voltage curves

8) Speed/Generated Voltage Characteristics

The use of permanent magnets in the rotors of low-speed synchronous motors means that a voltage is produced in proportion to the speed of rotation in the same way as with an AC rate generator when the motor is connected as shown in Fig-10 and the motor shaft is externally rotated (see Figures 11~13). Also, the speed of rotation can be accurately gauged by determining the frequency of the generated voltage.



$$V_{\text{gray-pale blue}} = \sqrt{2} V_{\text{gray-red}}$$

$$= \sqrt{2} V_{\text{pale blue-red}}$$

$$f \text{ [Hz]} = 5/6 N \text{ [r.p.m.]}$$

V: Generated Voltage [V]

f: Frequency of generated voltage [Hz]

N: Speed [r.p.m.]

Fig-10:

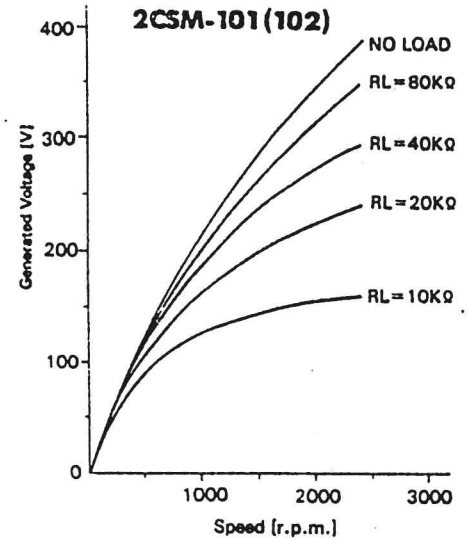


Fig-11: Speed/generated voltage curve

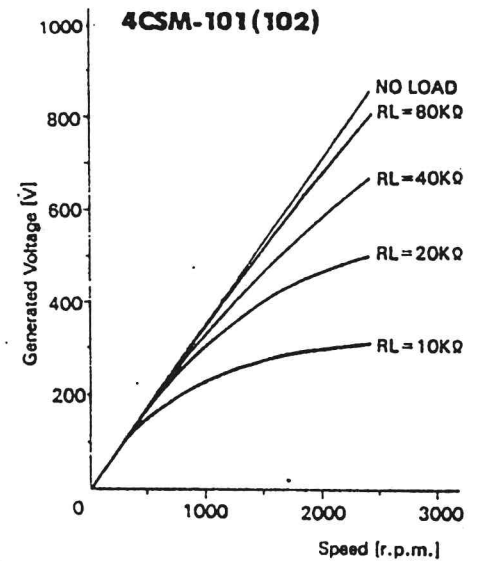


Fig-12: Speed/generated voltage curve

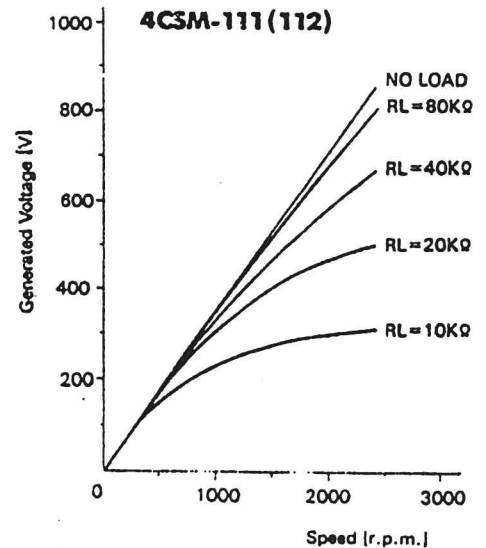


Fig-13: Speed/generated voltage curve

Model **E2E**

PROXIMITY SWITCH

INSTRUCTION MANUAL

■ AVAILABLE TYPES [E2E-□]: Add the appropriate code when placing your order, e.g., E2E-CR8C1]

• DC SWITCHING TYPE Table 1

Type	Size		M5		M8		M12		M18		M30	
	Shield	4dia.	Shield	5.4dia.	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield
Detecting distance [mm]	0.8	1	1.5	2	2	5	5	10	10	18	18	18
NPN	NO	-CR8C1	-X1R5E1	-X2ME1	-X2E1*	-X5ME1*	-X10ME1*	-X18ME1*	-X10ME1*	-X18ME1*	-X10E1*	-X18ME1*
	NC	-CR8C2	-X1R5E2	-X2ME2	-X2E2*	-X5ME2*	-X10ME2*	-X18ME2*	-X10ME2*	-X18ME2*	-X10E2*	-X18ME2*
PNP	NO	-CR8B1	-X1B1	-X2MF1	-X2F1*	-X5MF1*	-X10MF1*	-X18MF1*	-X10MF1*	-X18MF1*	-X10F1*	-X18MF1*
	NC	-CR8B2	-X1B2	-X2MF2	-X2F2*	-X5MF2*	-X10MF2*	-X18MF2*	-X10MF2*	-X18MF2*	-X10F2*	-X18MF2*

• AC SWITCHING TYPE Table 2

Type	Size		M8		M12		M18		M30	
	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield
Detecting distance(mm)	1.5	2	2	5	5	10	10	18	18	18
Short-circuit protection	Not provided	-X1R5Y1	-X2MY1	-X2Y1*	-X5MY1*	-X5Y1*	-X10MY1*	-X18MY1*	-X10MY1*	-X18MY1*
	Provided	-X1R5Y2	-X2MY2	-X2Y2*	-X5MY2*	-X5Y2*	-X10MY2*	-X18MY2*	-X10MY2 - 53*	-X18MY2 - 53*

NOTE: (1) Non-shield M8 type is also available, with a detecting distance of 2mm [E2E-X2M□□ and E2E-X2MY□□]. Please contact OMRON for details.
 (2) When ordering AC switching type conforming to UL and CSA standards, add suffix code "US".
 (3) The types identified with an asterisk are available with different frequencies, when using two sensors adjacent to each other.
 (Add suffix "5" to the part number when placing your order.)

■ DIMENSIONS [Unit: mm]

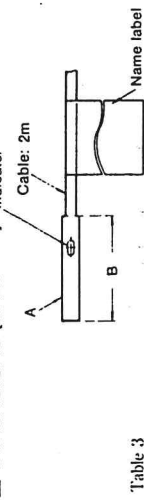


Table 3

Type	A	B	Name label
E2E-CR8C(B)□	4dia	25	B
E2E-C1C(B)□	5.4dia	25	B

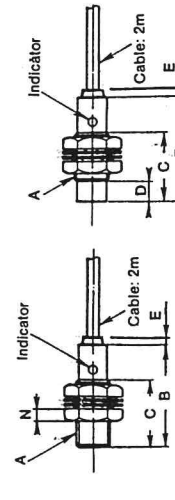


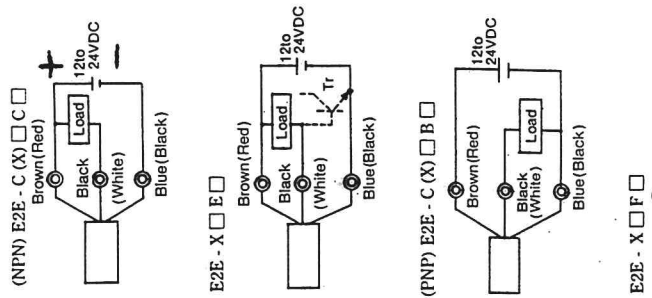
Table 4

Type	A	B	C	D	E	N
E2E-X1C(B)□	M5P=0.5	25	15	—	—	4
E2E-X1R5E(F)□	M8P=1.0	30	20	—	—	4
E2E-X1R5Y□	M8P=1.0	40	30	—	—	4
E2E-X2ME(F)□	M8P=1.0	30	20	5	—	4
E2E-X2MY□	M8P=1.0	40	30	5	—	4
E2E-X2E(F)□	M12P=1.0	35	24	—	—	3
E2E-X2Y□	M12P=1.0	40	29	—	—	3

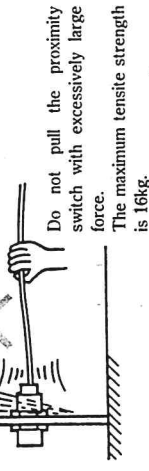
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■ CONNECTIONS

DC switching



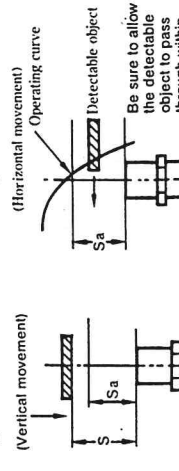
Do not pull the proximity switch with excessively large force.



Do not allow the sensor to make contact with a detectable object of a hard substance of do not apply shock to the sensor.

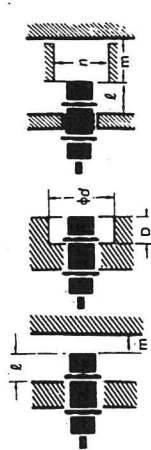
How to determine setting distance (for stable operation)
 • The detecting distance and setting distance of the proximity switch will vary depending on the shape size and material of a object to be detected. Therefore confirm the proper detecting and setting distance beforehand.

When a detectable object is smaller than the standard detectable object (iron), the detecting distance will become shorter. However the detecting distance will not become longer even if an object larger than the standard detectable object is used.



• Effects of surrounding metals

When a metallic object other than the object to be detected exists in the area surrounding the detecting head the proximity switch may be affected by the surrounding metal and may not release properly. Even if the proximity switch releases properly, change in the detecting distance may occur by temperature, etc. Therefore, be sure to provide a minimum distance from the surrounding metallic object, as specified in Table 9.



Effects of surrounding metals [Unit: mm] Table 8

Item	E2E-CR8		E2E-X1C		E2E-X1R5		E2E-X2M		E2E-X2MY		E2E-X10		E2E-X18	
	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield	Shield	Non-Shield
ℓ	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	4	5.4	8	12	18	30	24	40	55	90	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	5	15	22	30
m	2.4	3	4.5	8	20	40	8	20	40	7	20	40	7	20
n	6	8	12	18	27	45	24	36	54	9	24	36	54	9

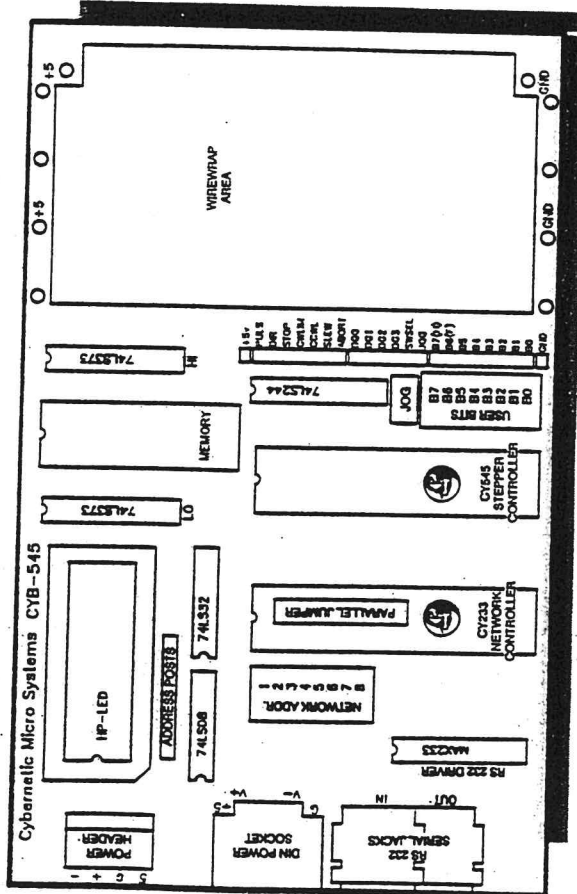
• Mutual interference
 When plural proximity switches are used, the juxtaposed switches may malfunction due to mutual interference.

The CYB-545 Prototyping Board

The CYB-545 Prototyping Board implements the Example Circuit - Maximum configuration as discussed earlier, supporting all features of the CY545. The CY545 may communicate serially with the host over an RS232 interface using the RJ11 jacks, while parallel communications are supported on a 20 pin header.

Multiple axes or networked controllers are supported using the CY233 Network Controller. The CY233 communicates with the CY545 over the Parallel bus.

This board also contains the interface circuits to support an HP or Siemens 8 character LED, for displaying parameter values, prompts, and messages. Up to 256K bits (32Kx8) of memory are addressable at the memory socket, which can accept Prom, Eprom, or EEPROM. It is possible for such a system to operate without the use of a host computer. The CY545 with local memory can contain the routines required to run the system, while the display provides the mechanism for system control by the operator.



A Wirewrap area is provided for implementation of thumbwheel switches, driver circuits, or other custom circuitry. Based on the single height VME format (100mm x 160mm, approximately 4" x 6.3"), the board requires only +5v (@ 650 mA). The RS232 level voltages are generated by the Max233 on the board.

The basic board is provided in kit form, with all parts necessary to assemble a working board. Separate options are available, including an LED Display, Memory EEPROM, CY233 Network Controller Chip, power supply, and serial cable.

CYS-545 Panel Software

The CYS-545 uses an IBM-PC/COM port to directly communicate with the CYB-545. Enter change, or read back stepping parameters; write and save external programs to EEPROM; or read and edit the externally stored program. As a learning tool, the software filters each command for appropriateness and proper format, and the help screens include command summaries and a pinout diagram.

CY545 Pin Configuration

40	PULSE/	←	1
39	CCW	←	2
38	STOPPED	←	3
37	CW_LIMIT/	←	4
36	CCW_LIMIT/	←	5
35	JOG	←	6
34	SLEW/	←	7
33	INHIB_ABORT/	←	8
32	RESET	←	9
31	RxD	←	10
30	TxD	←	11
29	SW_SEL/	←	12
28	IO_REQ/	←	13
27	XMEM_SEL/	←	14
26	BUSY/	←	15
25	WR/	←	16
24	RD/	←	17
23	XTAL2	←	18
22	XTAL1	←	19
21	VSS	←	20

Step pulse output, one pulse per step
 Step direction
 Motion Status, low while stepping
 Clockwise step limit reached
 Counter Clockwise step limit reached
 Manual stepping control
 Slew indicator signal
 External motion control
 CY545 hardware reset, active high pulse
 Received serial data into CY545
 Transmitted serial data from CY545
 Switch select
 Parallel handshake input signal
 External local memory select
 Parallel handshake acknowledgement
 Write strobe
 Read strobe
 Crystal connection
 Crystal or external clock circuit
 Power supply common

40	VCC	←	1
39	D0	←	2
38	D1	←	3
37	D2	←	4
36	D3	←	5
35	D4	←	6
34	D5	←	7
33	D6	←	8
32	D7	←	9
31	TEST	←	10
30	ALE	←	11
29	RESERVED	←	12
28	USERB7	←	13
27	USERB6	←	14
26	USERB5	←	15
25	USERB4	←	16
24	USERB3	←	17
23	USERB2	←	18
22	USERB1	←	19
21	USERB0	←	20

+ 5 volt power supply input
 Parallel data bus, bit 0, LSB
 Parallel data bus, bit 1
 Parallel data bus, bit 2
 Parallel data bus, bit 3
 Parallel data bus, bit 4
 Parallel data bus, bit 5
 Parallel data bus, bit 6
 Parallel data bus, bit 7, MSB
 Internal test signal, connect to Vcc
 Address latch enable
 Reserved signal, not used by CY545
 User selectable function, bit 7 or HP_SEL/
 User selectable function, bit 6 or FPL/ or CTS/
 User selectable function, bit 5
 User selectable function, bit 4
 User selectable function, bit 3
 User selectable function, bit 2
 User selectable function, bit 1
 User selectable function, bit 0

4 Command Summary 4

CY545 Command Summary

The following is a list of CY545 commands, including the command letter and argument structure. Arguments without a suffix should be single byte numeric values up to 255, while arguments with a "16" suffix may be two byte numbers up to 65535, and arguments with a "24" suffix may be three byte numbers up to 16777215. Commands are entered as the single upper case ASCII letter, followed by a space, and the argument value. Multiple arguments may be separated by a space or comma. The command ends with a carriage return character. Commands without arguments simply use the command letter, followed directly by the carriage return.

Command	Function
A Pos24	At position, sets current step position
B Bit	Bit set or clear of user selectable bits
C	Set Continuous step mode
D Del16	Delay for specified milliseconds
E	Enter following commands to external memory
F Rate	Specify First step rate
G	Go step, relative mode
H Bit	Seek Home, using specified bit
I	Initialize CY545, perform software reset
J Addr	Jump to byte address of current memory page
L Cnt,Addr	Loop to byte address for specified count
N Num24	Set Number of steps for relative motions
O Mode	Set Operating mode of CY545
P Pos24	Step to specified absolute Position
Q	Quit entering commands to external memory
R Rate	Specify slewing step Rate
S Slope	Specify acceleration Slope value
T Bit,Addr	Loop to address 'til bit matches value
U	Reserved command
V	Reserved command
W Bit	Wait for specified bit to match value
X	Execute external memory commands
Y Addr16	Set external memory address pointer
Z Cnt16,Addr	ZillionLoop to byte address for 16 bit count
+	Select CW direction for relative motions
-	Select CCW direction for relative motions
/	Negate prefix used with Bit commands
?	Query specified command parameter value
0	Stop execution of commands from memory
I Addr,Cnt,D1,...,Dn	Special HP Display support command
"String"	Display all characters between quotes

STEPPER MOTOR DRIVING

Dedicated integrated circuits have dramatically simplified stepper motor driving. To apply these ICs designers need little specific knowledge of motor driving techniques, but an understanding of the basics will help in finding the best solution. This note explains the basics of stepper motor driving and describes the drive techniques used today.

From a circuit designer's point of view stepper motors can be divided into two basic types: unipolar and bipolar.

A stepper motor moves one step when the direction of current flow in the field coil(s) changes, reversing the magnetic field of the stator poles. The difference between unipolar and bipolar motor lies in the way that this reversal is achieved (Figure 1):

Fig. 1a - BIPOLAR - with one field coil and two chargeover switches that are switched in the opposite direction.

Fig. 1b - UNIPOLAR - with two separate field coils and are chargeover switch.

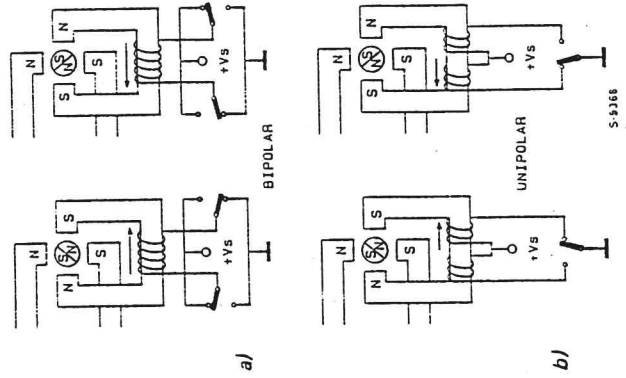
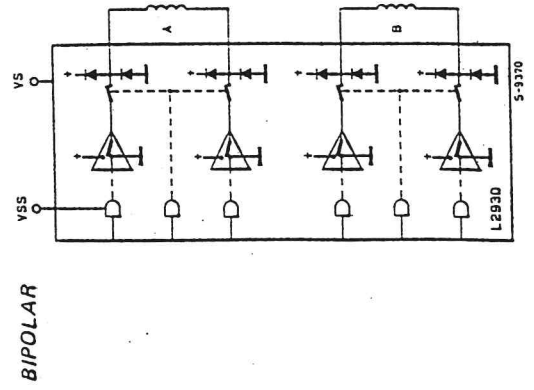
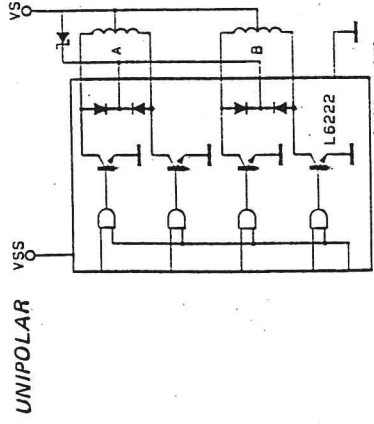


Fig. 2 - ICs for unipolar and bipolar driving



The advantage of the bipolar circuit is that there is only one winding, with a good bulk factor (low winding resistance). The main disadvantages are the two changeover switches because in this case more semiconductor switches are needed.

The unipolar circuit needs only one changeover switch. Its enormous disadvantage is, however, that a double bifilar winding is required. This means that at a specific bulk factor the wire is thinner and the resistance is much higher. We will discuss later the problems involved.

Unipolar motors are still popular today because the drive circuit appears to be simpler when implemented with discrete devices. However with the integrated circuits available today bipolar motors can be driven with no more components than the unipolar motors. Figure 2 compares integrated unipolar and bipolar devices.

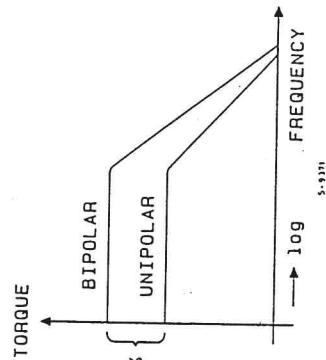
BIPOLAR PRODUCES MORE TORQUE

The torque of the stepper motor is proportional to the magnetic field intensity of the stator windings. It may be increased only by adding more windings or by increasing the current.

A natural limit against any current increase is the danger of saturating the iron core, though this is of minimal importance. Much more important is the maximum temperature rise of the motor, due to the power loss in the stator windings. This shows one advantage of the bipolar circuit, which, compared to unipolar systems, has only half of the copper resistance because of the double cross section of the wire. The winding current may be increased by the factor $\sqrt{2}$ and this produces a direct proportional effect on the torque. At their power loss limit bipolar motors thus deliver about 40% more torque (Fig. 3) than unipolar motors built on the same frame.

If a higher torque is not required, one may either reduce the motor size or the power loss.

Fig. 3 - Bipolar motors deliver more torque than unipolars



CONSTANT CURRENT DRIVING

In order to keep the motor's power loss within a reasonable limit, the current in the windings must be controlled.

A simple and popular solution is to give only as much voltage as needed, utilizing the resistance (R_L) of the winding to limit the current (Fig. 4a). A more complicated but also more efficient and precise solution is the inclusion of a current generator (Fig. 4b), to achieve independence from the winding resistance. The supply voltage in Fig. 4b has to be higher than the one in Fig. 4a. A comparison between both circuits in the dynamic load/working order shows visible differences.

Fig. 4 - Resistance current limiter (a) and current generator limiting

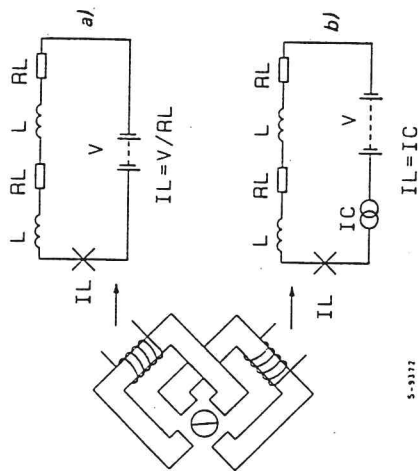
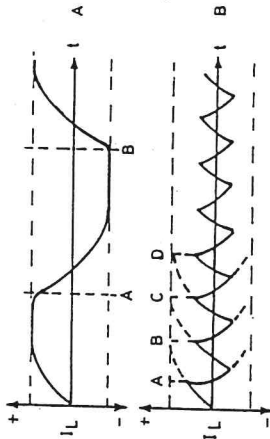


Fig. 5 - At high step frequencies the winding current cannot reach its setting value because of the continuous direction change



It has already been mentioned that this power of the motor is, among others, proportional to the winding current.

In the dynamic working order a stepper motor changes poles of the winding current in the same stator winding after two steps. The speed with which the current changes its direction in the form of an exponential function depends on the specified inductance, the coil resistance and on the voltage. Fig. 5a shows that at a low step rate the winding current I_L reaches its nominal value V/R_L before the direction is changed. However, if the poles of the stator windings are changed more often, which corresponds to a high step fre-

quency, the current no longer reaches its saturating value because of the limited change time; the power and also the torque diminish clearly at increasing number of revolutions (Fig. 5).

MORE TORQUE AT A HIGHER NUMBER OF REVOLUTIONS

Higher torque at faster speeds are possible if a current generator as shown in Fig. 4b is used. In this application the supply voltage is chosen as high as possible to increase the current's rate of change. The current generator itself limits only the phase current and becomes active only the moment in which the coil current has reached its set nominal value. Up to this value the current generator is in saturation and the supply voltage is applied directly to the winding.

Fig. 6, shows that the rate of the current increase is now much higher than in Figure 5. Consequently at higher step rates the desired current can be maintained in the winding for a longer time. The torque decrease starts only at much higher speeds.

Fig. 7 shows the relation between torque and speed in the normal graphic scheme, typical for the stepper motor. It is obvious that the power increases in the upper torque range where it is normally needed, as the load to be driven draws most energy from the motor in this range.

Fig. 6 - With a step current slew it is not a problem to obtain, even at high step frequencies sufficient current in windings.

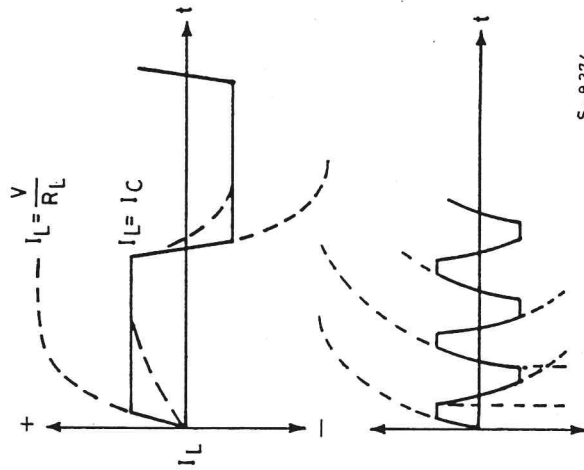
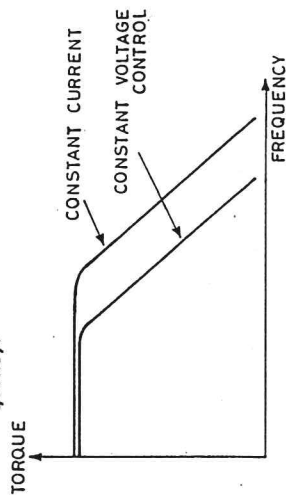


Fig. 7 - Constant current control of the stepper motor means more torque at high frequency.



EFFICIENCY - THE DECISIVE FACTOR

The current generator combined with the high supply voltage guarantees that the rate of change of the current in the coil is sufficiently high. At the static condition or at low numbers of revolutions, however, this means that the power loss in the current generator dramatically increases, although the motor does not deliver any more energy in this range; the efficiency factor is extremely bad.

Help comes from a switched current regulation using the switch-transformer principle, as shown in Fig. 8. The phase winding is switched to the supply voltage until the current, detected across R_S , reaches the desired nominal value. At that moment the switch, formerly connected to $+V_S$, changes position and shorts out the winding. In this way the current is stored, but it decays slowly because of inner winding losses. The discharge time of the current is determined during this phase by a monostable or pulse oscillator. After this time one of the pole changing switches changes back to $+V_S$, starting an induction recharge and the clock-regulation-cycle starts again.

Since the only losses in this technique are the saturation loss of the switch and that of the coil resistance, the total efficiency is very high.

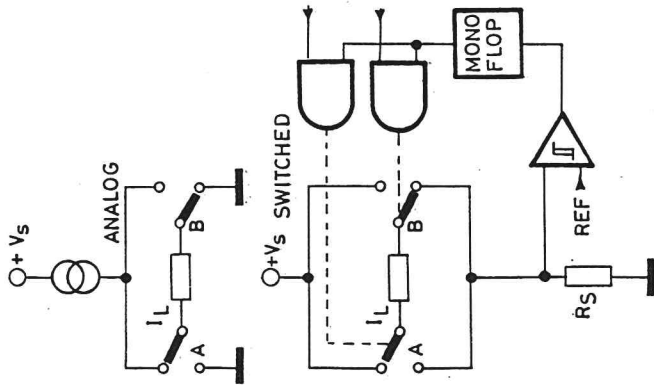
The average current that flows from the power supply line is less than the winding current due to the concept of circuit inversion. In this way also the power unit is discharged. This kind of phase current control that has to be done separately for each motor phase leads to the best ratio between the supplied electrical and delivered mechanical energy.

POSSIBLE IMPROVEMENTS OF THE UNIPOLAR CIRCUIT

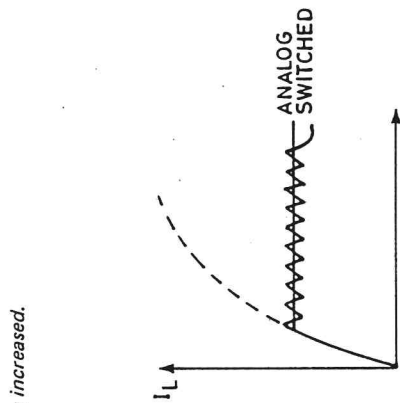
It would make no sense to apply the same principle to a stabilized current controlled unipolar circuit, as two more switches per phase would be necessary for the shortening out of the windings during the free phase and thus the number of components would be the same as for the bipolar circuit; and moreover, there would be the well known torque disadvantage.

From the economic point of view a reasonable and justifiable improvement is the "Bi-Level-Drive" (Fig. 9). This circuit concept works with two supply voltages; with every new step of the motor both windings are connected for a short time to a high supply voltage. This considerably increases the current rate of change and its behaviour corresponds more or less to the stabilized power principle. After a pre-determined time the switch opens, a no a lower supply voltage is con-

Fig. 8 - With switch mode current regulation efficiency is increased.



nected to the winding thru a diode. This kind of circuit by no means reaches the performance of the clocked stabilized power control as per Fig. 8, as the factors: distribution voltage oscillation, B.e.m.f., thermal winding resistance, as well as the separate coil current regulation are not considered, but it is this circuit that makes the simple unipolar R/L-control suitable for many fields of application.



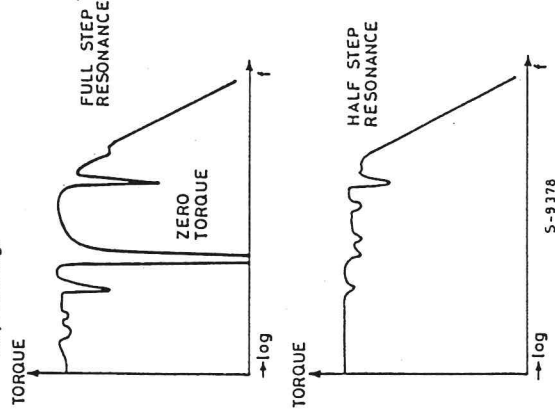
S-9376

ADVANTAGES AND DISADVANTAGES OF THE HALF-STEP

An essential advantage of a stepper motor operating at half-step conditions is its position resolution increased by the factor 2. From a 3.6 degree motor you achieve 1.8 degrees, which means 200 steps per revolution.

This is not always the only reason. Often you are forced to operate at half-step conditions in order to avoid that operations are disturbed by the motor resonance. These may be so strong that the motor has no more torque in certain step frequency ranges and loses completely its position (Fig. 10). This is due to the fact that the rotor of the motor, and the changing magnetic field of the stator forms a spring-mass-system that may be stimulated to vibrate. In practice, the load might deaden this system, but only if there is sufficient frictional force.

Fig. 10 - The motor has no more torque in certain step frequency ranges with full step driving.



S-9378

In most cases half-step operation helps, as the course covered by the rotor is only half as long and the system is less stimulated.

The fact that the half-step operation is not the dominating or general solution, depends on certain disadvantages:

- the half-step system needs twice as many clock-pulses as the full-step system; the clock-frequency is twice as high as with the full-step.
 - In the half-step position the motor has only about half of the torque of the full-step.
- For this reason many systems use the half-step operation only if the clock-frequency of the motor is within the resonance risk area.

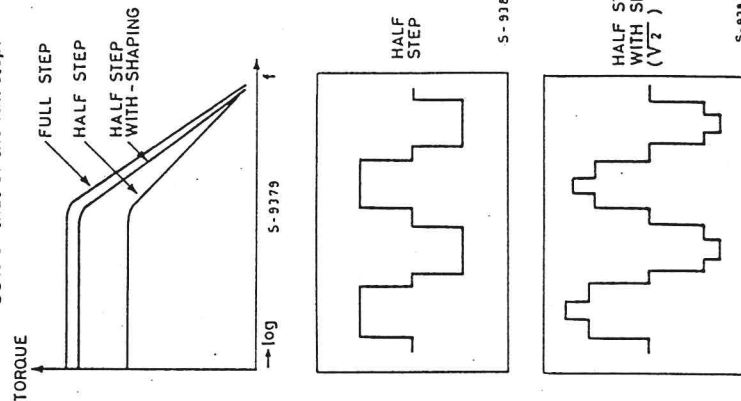
The dynamic loss is higher the nearer the load moment comes to the limit torque of the motor. This effect decreases at higher numbers of revolutions.

TORQUE LOSS COMPENSATION IN THE HALF-STEP OPERATION

It's clear that, especially in limit situations, the torque loss in half-step is a disadvantage. If one has to choose the next larger motor or one with a double resolution operating in full-step because of some insufficient torque percentages, it will greatly influence the costs of the whole system. In this case, there is an alternative solution that does not increase the costs for the bipolar chopping stabilized current drive circuit.

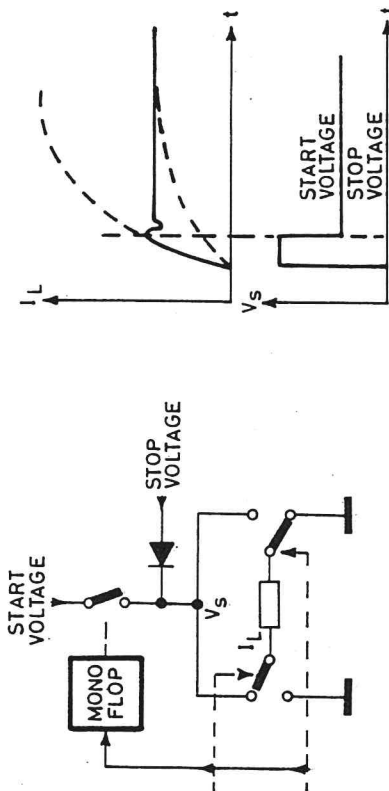
The torque loss in the half-step position may be compensated for by increasing the winding current by the factor $\sqrt{2}$ in the phase winding that remains active. This is also permissible if, according to the motor data sheet, the current limit has been reached, because this limit refers always to the contemporary supply with current in both windings in the full-step position. The factor $\sqrt{2}$ increase in current doubles the stray power of the

Fig. 11 - Half step driving with shaping allows to increase the motor's torque to about 95% of that of the full step.



S-9380

Fig. 9 - At every new step of the motor, it is possible to increase the current rate with a bilevel circuit.



active phase. The total dissipated power is like that of the full-step because the non-active phase does not dissipate power.

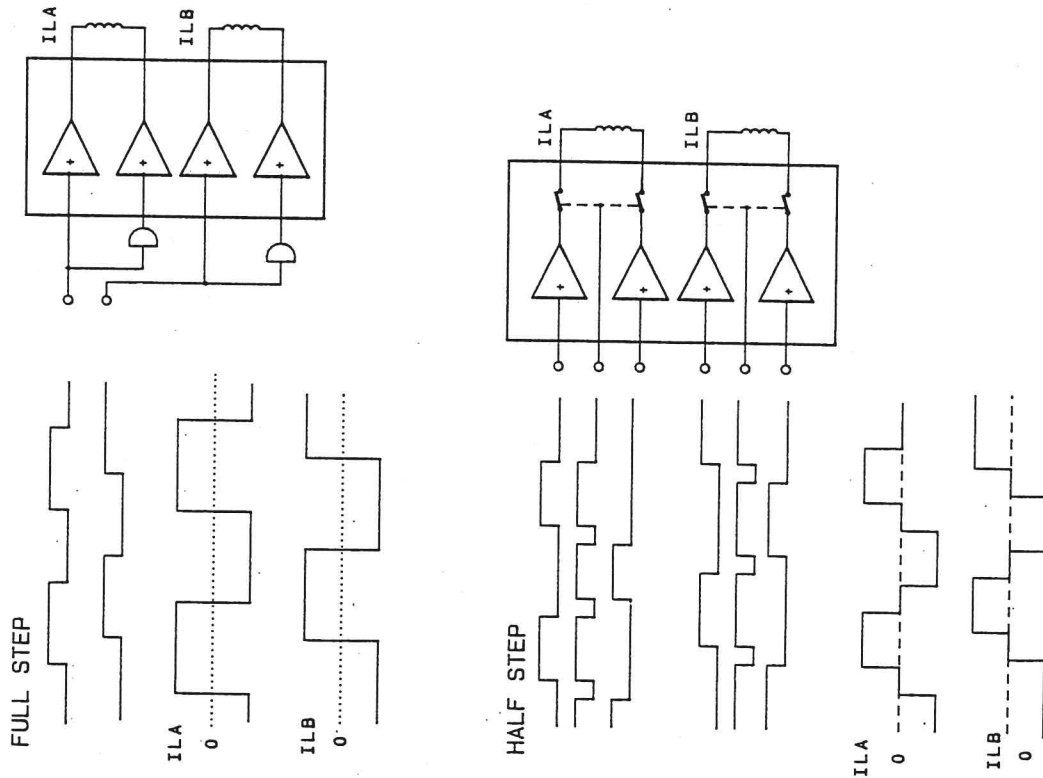
The resulting torque in the half-step position amounts to about 90% of that of the full-step, that means dynamically more than 95% torque compared to the pure full-step; a neglectable factor.

The only thing to avoid is stopping the motor at

limit current conditions in a half-step position because it would be like a winding thermal phase overload concentrated in one.

The best switch-technique for the half-step phase current increase will be explained in detail later on. Fig. 11 shows the phase current of a stepping motor in half-step control with an without phase current increase and the pertinent curves of step frequency and torque.

Fig. 12 - Only two signals for full step driving are necessary while four (six if three-state is needed on the outputs stages) for half step.



DRIVE SIGNALS FOR THE MICRO ELECTRONIC

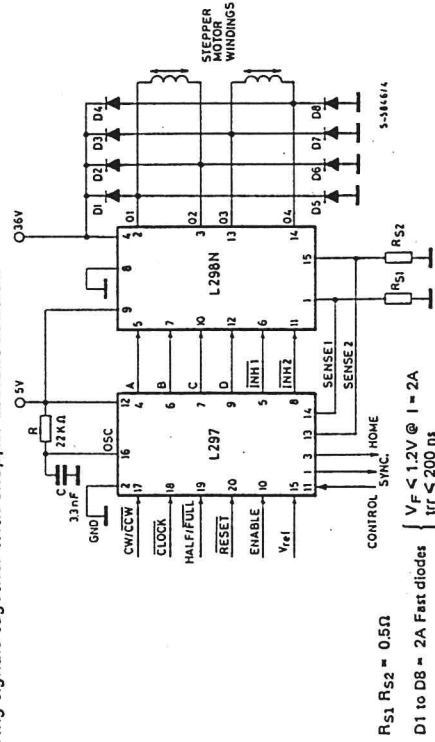
A direct current motor runs by itself if you supply it with voltage, whereas the stepping motor needs the commutation signal in for of several separated but linkable commands. In 95% of the applications today, the origin of these digital commands is a microprocessor-system.

In its simplest form, a full-step control needs only two rectangular signals in quadrature. According to which phase is leading, the motor axis rotates clockwise or counter-clockwise, whereby the rotation speed is proportional to the clock frequency.

In the half-step system the situation becomes more complicated. The minimal two control signals become four control signals. In some conditions as many as six signals are needed, if the Tri-state-command for the phase ranges without current, necessary for high motor speeds, may not be obtained from the 4 control signals. Fig. 12 shows the relationship between the phase current diagram and the control signal for full and half-step.

Since all signals in each mode are in defined relations with each other, it is possible to generate

Fig. 13 - The L297 avoids the use of complicated standard logic to generate both full and half-step driving signals together with chopper current control.



them using standard logic. However, if the possibility to choose full and half-step is desired, a good logic implementation becomes quite expensive and an application specific integrated circuit would be better. Such an application specific integrated circuit could reduce the number of outputs required from a microprocessor from the 6 required to 3 static and dynamic control line.

A typical control circuit that meets all these requirements is the L297 unit (Fig. 13).

Four signals control the motor in all operations:

1. **CLOCK:** The clock signal, giving the stepping command
2. **RESET:** Puts the final level signals in a defined start position.
3. **DIRECTION:** Determines the sense of rotation of the motor axis
4. **HALF/FULL:** Decides whether to operate in full or in half-step.

Another inhibit input allows the device to switch the motor output into the Tri-state-mode in order to prevent undesired movements during undefined operating conditions, such as those that could occur during.

SWITCH-MODE CURRENT REGULATION

The primary function of the current regulation circuit is to supply enough current to the phase windings of the motor, even at high step rates.

The functional blocks required for a switchmode current control are the same blocks required in switching power supplies; flip-flops, comparators; and an oscillator are required. These blocks can easily be included in the same IC that generates the phase control signals. Let us consider the implementation of chopper current control in the L297.

The oscillator on pin 16 of the L297 resets the two flip-flops at the start of each oscillator period. The

flip-flop outputs are then combined with the outputs of the translator circuit to form the 6 control signals supplied to the power bridge (L298).

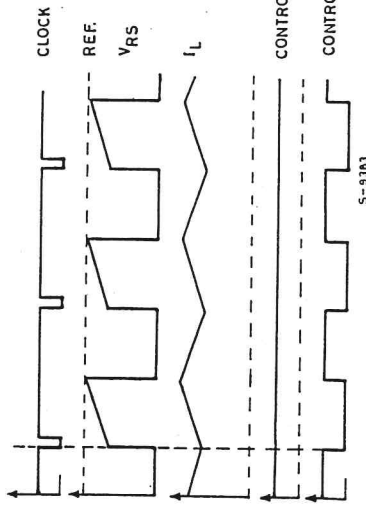
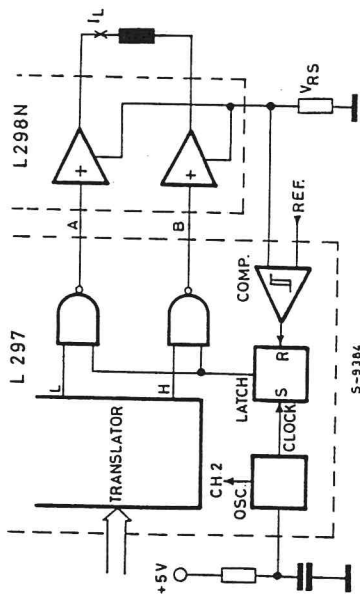
When activated, by the oscillator, the current in the winding will raise, following the L/R time constant curve, until the voltage across the sense resistor (pin 1, 15 of L298) is equal to the reference voltage input. (pin 15, L297) the comparator then sets the flip-flop, causing the output of the L297 to change to an equiphase condition, thus effectively putting a short circuit across the phase winding. The bridge is activated into a diagonally conductive state when the oscillator resets the flip-flop at the start of the next cycle.

Using a common oscillator to control both current regulators maintains the same chopping frequency for both, thus avoiding interference between the two.

The functional block diagram of the L297 and the power stage (L298) are shown in Figure 14 along with the operating wave forms.

An important characteristic of this circuit implementation is that, during the reset time, the flip-flops are kept reset. The reset time can be selected by selecting the impedance of the R/C network of pin 16. In this way, the current spike and noise across the sense resistors that may occur during switching will not cause a premature setting of the flip-flop. Thus the recovery current spike of the protection diodes can be ignored and a filter in the sense line is avoided.

Fig. 14 - Two ICs and very few external components provide complete microprocessor to bipolar stepper motor interface.



THE RIGHT PHASE CURRENT FOR EVERY OPERATING CONDITION

The Chopper principle of the controller unit reveals that the phase current in the motor windings is controlled by two data: the reference voltage at pin 15 of the controller and the value of the sense resistance at pins 1 and 15 of the L298, that is $I_L = V_{REF}/R_S$. By changing V_{REF} it is very easy to vary the current within large limits. The only question is for which purpose and at which conditions.

More phase current means more motor torque, but also higher energy consumption.

With two resistance and one small signal transistor as changeover switch for the reference input. With another resistance and transistor it is possible to resolve 2 Bits and consequently 4 levels. That during a positioning operation.

Fig. 15 - Because of the set-dominant latch inside the L297 it is possible to hide current spikes and noise across the sense resistors thus avoiding external filters.

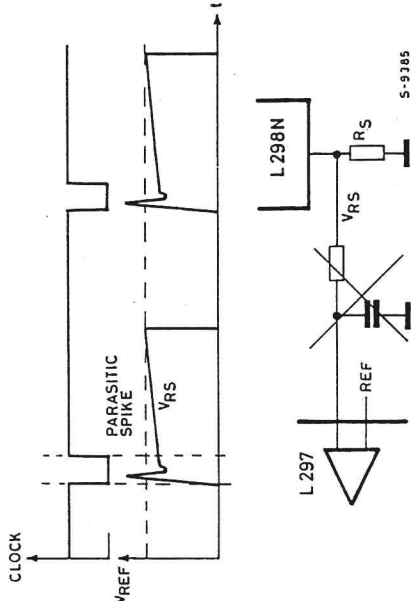
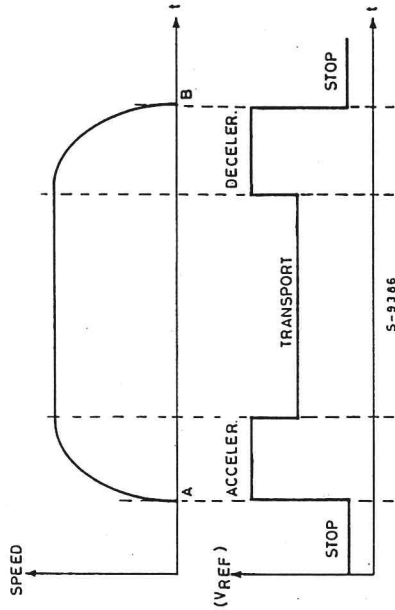


Fig. 16 - More energy is needed during the acceleration and break phases compared to the continuous operation, neutral or stop position.



HIGH MOTOR CLOCK RESETS IN THE HALF-STEP SYSTEM

In the half-step position one of the motor phases has to be without current. If the motor moves from a full-step position into a half-step position, this means that one motor winding has to be completely discharged. From the logic diagram this means for the high level bridge an equivalent status of the input signals A/B, for example in the HIGH-status. For the coil this means short circuit (Fig. 17 up) and consequently a low reduction of the current. In case of high half-step speeds the short circuit discharge time constant of the phase winding is not sufficient to discharge the

is sufficient for all imaginable causes.

With another resistance and transistor it is possible to resolve 2 Bits and consequently 4 levels. That during a positioning operation.

Fig. 16 - More energy is needed during the acceleration and break phases compared to the continuous operation, neutral or stop position.

current during the short half-step phases. The current diagram is not neat, the half step is not carried out correctly (Fig. 17 center).

For this reason the L297 controller-unit generates an inhibit-command for each phase bridge, that switches the specific bridge output in the half-step position into Tri-state. In this way the coil can start swinging freely over the external recovery diodes and discharge quickly. The current decrease rate of change corresponds more or less to the increase rate of change (Fig. 17 below). In case of full-step operation both inhibit-outputs of the controller (pin 5 and 8) remain in the HIGH-status.

Fig. 17 - The inhibit signal turns off immediately the output stages allowing thus a faster current decay (mandatory with half-step operation).

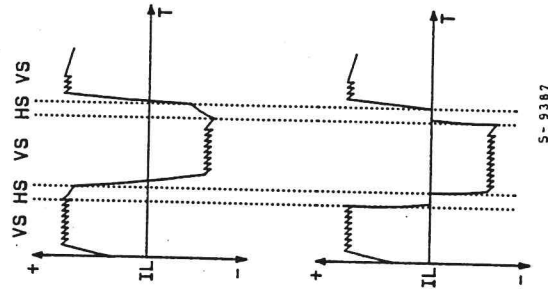
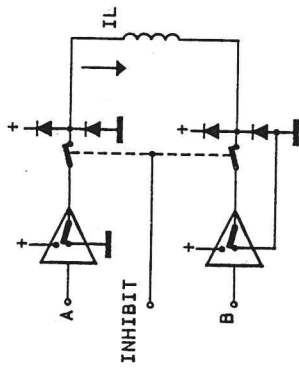
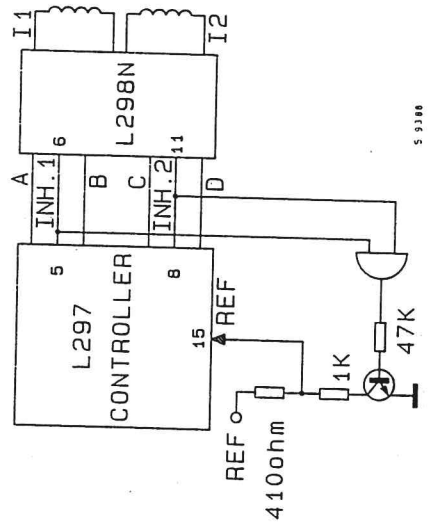


Fig. 18 - With this configuration it is possible to obtain half-step with shaping operation and therefore more torque.



MORE TORQUE IN THE HALF-STEP POSITION

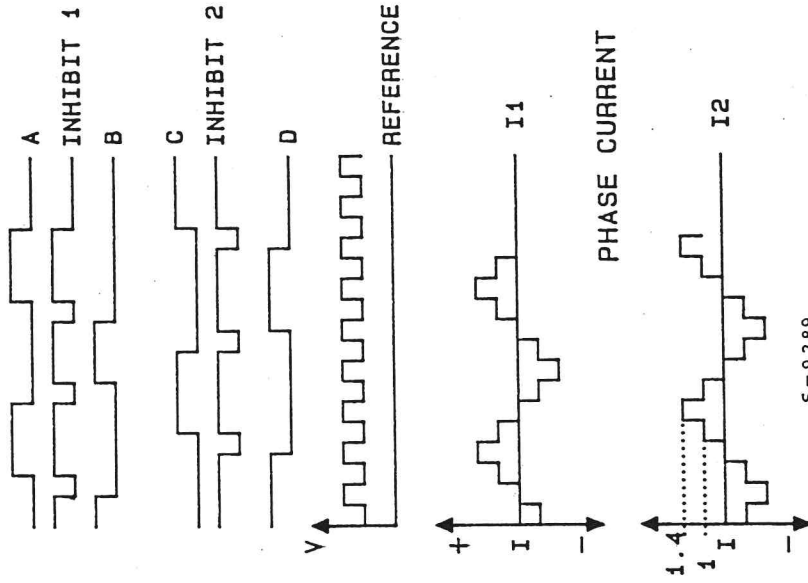
A topic that has already been discussed in detail. So we will limit our considerations on how it is carried out, in fact quite simply because of the reference voltage controlled phase current regulation.

With the help of the inhibit-signals at outputs 5 and 8 of the controller, which are alternatively active only when the half-step control is programmed, the reference voltage is increased by

the factor 1.41 with a very simple additional wiring (Fig. 18), as soon as one of the two inhibit-signals switches LOW. This increases the current in the active motor phase proportionally to the reference voltage and compensates the torque loss in this position. Fig. 19 shows clearly that the diagram of the phase current is almost sinusoidal, in principle the ideal form of the current graph.

To sum up we may say that this half-step version offers most advantages. The motor works with poor resonance and a double position resolution at a torque, that is almost the same as that of the full-step.

Fig. 19 - The half-step with shaping positioning is achieved by simply changing reference voltages.



BETTER GLIDING THAN STEPPING

If a stepper motor is supposed to work almost gliding and not step by step, the form of the phase current diagram has to be sinusoidal.

The advantages are very important:

- no more phenomena of resonance
- drastic noise reduction
- connected gears and loads are treated with care

- the position resolution may be increased further.

However, the use of the L297 controller-unit described until now is no longer possible of the more complicated form of the phase current diagram the Controller may become simpler in its functions.

Fig. 20 shows us an example with the L6505 unit. This IC contains nothing more than the clocked phase current regulation which works according to

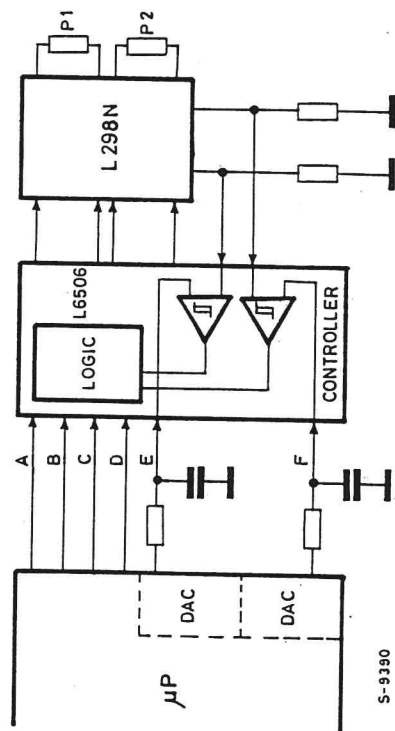
the same principle as L297. The four control signals emitting continuously a full-step program are now generated directly by the microprocessor. In order to obtain a sinusoidal phase current course the reference voltage inputs of the Controller are modulated with sinusoidal half-waves.

The microprocessor that controls the direction of the current phase with the control signals also generates the two analog signals.

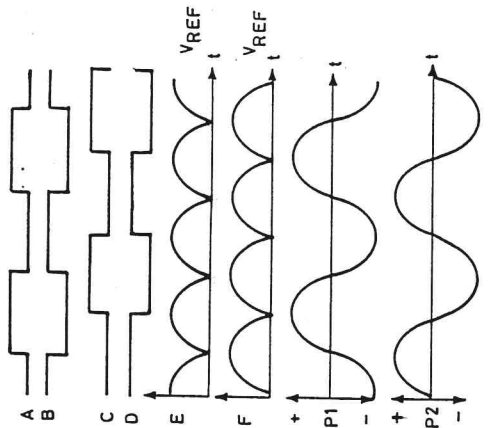
For many applications a microprocessor with dedicated digital to analog converters can be chosen. Eliminating the need for separate D/A circuits.

In case of higher motor revolutions it is more convenient to operate only in full-step, since harmonic control is no longer an advantage as the current has only a triangular waveform in the motor winding.

Fig. 20 - L6506 unit gives the possibility to modulate separately the two reference voltage inputs in order to obtain a sinusoidal phase current.



S-9390



S-9423

PRECISION OF THE MICRO STEP

Any desired increase of the position resolution between the full step position has its physical limits. Those who think it is possible to resolve a 7.2° - stepper motor to 1.8° with the same precision as a 1.8° - motor in full-step will be received, as there are several limits:

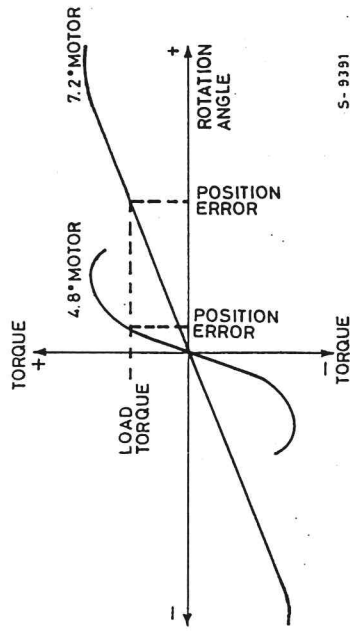
The rise rate of the torque diagram corresponding to the twisting angle of the rotor for the 7.2° - motor is flatter by a factor of 4 than for the original 1.8° - motor. Consequently with friction or load moment, the position error is larger

(Fig. 21).

For most of the commercial motors there isn't a sufficiently precise, linear relationship between a sinusoidal-current-diagram and an exact micro step angle. The reason is a dishomogeneous magnetic field between the rotor and the two stator fields.

Above all, problems have to be expected with motors with high pole feeling. However, there are special stepper motors in which an optimized micro step operation has already been considered during the construction phase.

Fig. 21 - Better resolution is achieved with low degree motor but more torque is delivered with high degree motor.



S-9391

CONCLUSIONS

The above described application examples of modern integrated circuits show that output and efficiency of stepper motors may be remarkably increased without any excessive expense increase

like before.

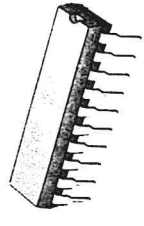
Working in limit areas, where improved electronics with optimized drive sequences allow the use of less expensive motors, it is even possible to obtain a cost reduction.

L297
L297A



STEPPER MOTOR CONTROLLERS

and on-chip PWM chopper circuits permit switch-mode control of the current in the windings. A feature of this device is that it requires only clock, direction and mode input signals. Since the phase are generated internally the burden on the microprocessor, and the programmer, is greatly reduced. Mounted in a 20-pin plastic package, the L297 can be used with monolithic bridge drives such as the L298N or L293E, or with discrete transistors and darlingtonts. The L297A also includes a clock pulse doubler.



DIP-20 Plastic
(0.4)
ORDERING NUMBERS: L297-L297A

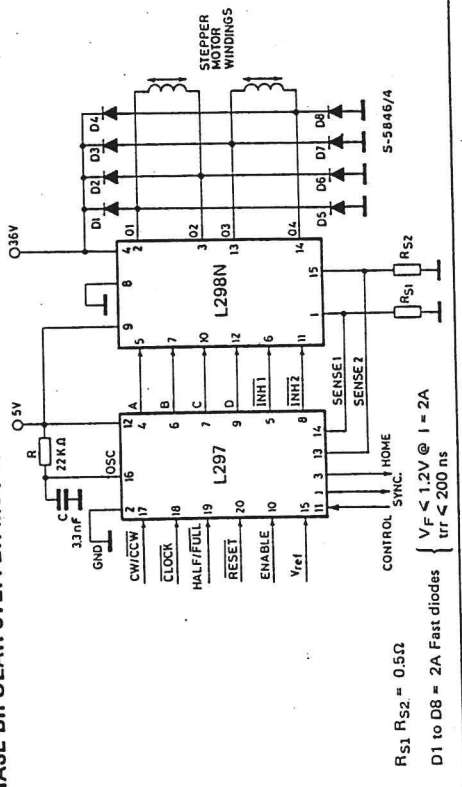
- NORMAL/WAVE DRIVE
- HALF/FULL STEP MODES
- CLOCKWISE/ANTICLOCKWISE DIRECTION
- SWITCHMODE LOAD CURRENT REGULATION
- PROGRAMMABLE LOAD CURRENT
- FEW EXTERNAL COMPONENTS
- RESET INPUT & HOME OUTPUT
- ENABLE INPUT
- STEP PULSE DOUBLER (L297A ONLY)

The L297 Stepper Motor Controller IC generates four phase drive signals for two phase bipolar and four phase unipolar step motors in microcomputer-controlled applications. The motor can be driven in half step, normal and wave drive modes

ABSOLUTE MAXIMUM RATINGS

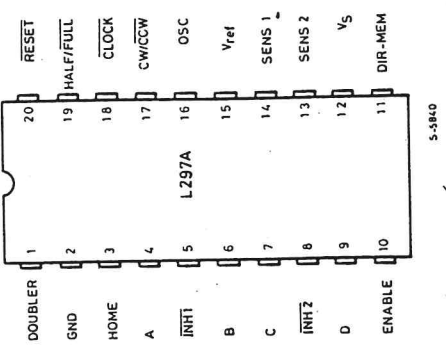
V_s	Supply voltage	10	V
V_i	Input signals	7	V
P_{tot}	Total power dissipation ($T_{amb} = 70^\circ\text{C}$)	1	W
T_{stg}, T_j	Storage and junction temperature	-40 to +150	$^\circ\text{C}$

TWO PHASE BIPOLAR STEPPER MOTOR CONTROL CIRCUIT



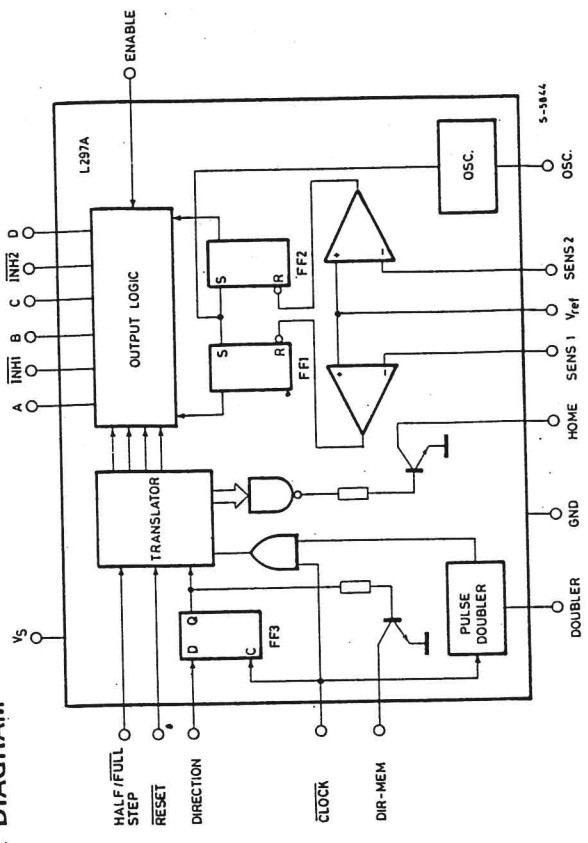


CONNECTION DIAGRAM



5-5840

BLOCK DIAGRAM

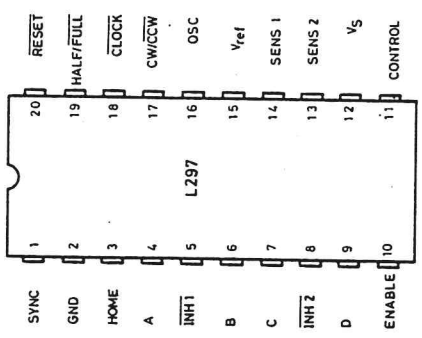


THERMAL DATA

$R_{th} J-amb$	Thermal resistance junction-ambient	max.	80	$^{\circ}C/W$
----------------	-------------------------------------	------	----	---------------

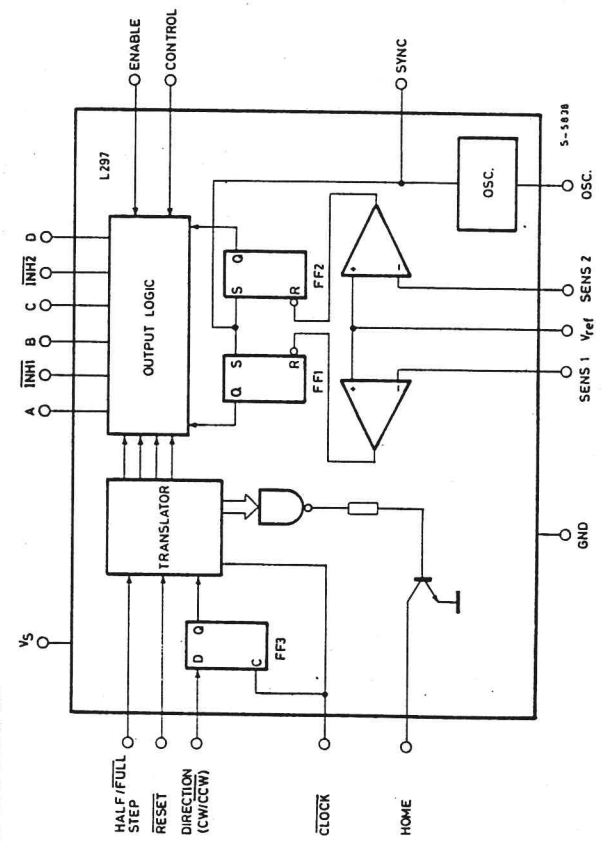


CONNECTION DIAGRAM



5-5839

BLOCK DIAGRAM



PIN FUNCTIONS - L297

N°	NAME	FUNCTION
1	SYNC	Output of the on-chip chopper oscillator. The SYNC connections of all L297s to be synchronized are connected together and the oscillator components are omitted on all but one. If an external clock source is used it is injected at this terminal.
2	GND	Ground connection.
3	HOME	Open collector output that indicates when the L297 is in its initial state (ABCD = 0101). The transistor is open when this signal is active.
4	A	Motor phase A drive signal for power stage.
5	INH1	Active low inhibit control for driver stages of A and B phases. When a bipolar bridge is used this signal can be used to ensure fast decay of load current when a winding is de-energized. Also used by chopper to regulate load current if CONTROL input is low.
6	B	Motor phase B drive signal for power stage.
7	C	Motor phase C drive signal for power stage.
8	INH2	Active low inhibit control for drive stages of C and D phases. Same functions as INH1.
9	D	Motor phase D drive signal for power stage.
10	ENABLE	Chip enable input. When low (inactive) INH1, INH2, A, B, C and D are brought low.
11	CONTROL	Control input that defines action of chopper. When low chopper acts on INH1 and INH2; when high chopper acts on phase lines ABCD.
12	V _s	5V supply input.
13	SENS ₂	Input for load current sense voltage from power stages of phases C and D.

PIN FUNCTIONS - L297 (continued)

N°	NAME	FUNCTION
14	SENS ₁	Input for load current sense voltage from power stages of phases A and B.
15	V _{ref}	Reference voltage for chopper circuit. A voltage applied to this pin determines the peak load current.
16	OSC	An RC network (R to V _{CC} , C to ground) connected to this terminal determines the chopper rate. This terminal is connected to ground on all but one device in synchronized multi-L297 configurations. $f \approx 1/0.69 RC$, $R > 10 k\Omega$.
17	CW/CCW	Clockwise/counterclockwise direction control input. Physical direction of motor rotation also depends on connection of windings. Synchronized internally therefore direction can be changed at any time.
18	CLOCK	Step clock. An active low pulse on this input advances the motor one increment. The step occurs on the rising edge of this signal.
19	HALF/FULL	Half/full step select input. When high selects half step operation; when low selects full step operation. One-phase-on full step mode is obtained by selecting FULL when the L297's translator is at an even-numbered state. Two-phase-on full step mode is set by selecting FULL when the translator is at an odd numbered position. (The home position is designated state 1).
20	RESET	Reset input. An active low pulse on this input restores the translator to the home position (state 1, ABCD = 0101).

PIN FUNCTIONS - L297A

Pin function of the L297A are identical to those of the L297 except for pins 1 and 11.

FUNCTIONS

- | N° | NAME | FUNCTIONS |
|----|---------|--|
| 1 | DOUBLER | An RC network connected to this pin determines the delay between an input clock pulse and the corresponding ghost pulse. |
| 11 | DIR-MEM | Direction Memory. Inverted output of the direction flip flop. Open collector output. |

CIRCUIT OPERATION

The L297(A) is intended for use with a dual bridge driver, quad darlington array or discrete power devices in step motor driving applications. It receives step clock, direction and mode signals from the systems controller (usually a microcomputer chip) and generates control signals for the power stage.

The principal functions are a translator, which generates the motor phase sequences, and a dual PWM chopper circuit which regulates the current in the motor windings. The translator generates three different sequences, selected by the HALF/FULL input. These are normal (two phases energised), wave drive (one phase energised) and half-step (alternately one phase energised/two phases energised). Two inhibit signals are also generated by the L297 in half step and wave drive modes. These signals, which connect directly to the L298's enable inputs, are intended to speed current decay when a winding is de-energised. When the L297 is used to drive a unipolar motor the chopper acts on these lines.

An input called CONTROL determines whether the chopper will act on the phase lines ABCD or the inhibit lines INH1 and INH2. When the phase lines are chopped the non-active phase line of each pair (AB or CD) is activated (rather than interrupting the line then active). In L297 + L298 configurations this technique reduces dissipation in the load current sense resistors.

A common on-chip oscillator drives the dual chopper. It supplies pulses at the chopper rate which set the two flip-flops FF1 and FF2. When the current in a winding reaches the programmed peak value the voltage across the sense resistor (connected to one of the sense inputs SENS₁ or SENS₂) equals V_{ref} and the corresponding comparator resets its flip flop, interrupting the drive current until the next oscillator pulse arrives. The peak current for both windings is programmed by a voltage divider on the V_{ref} input.

Ground noise problems in multiple configurations can be avoided by synchronising the chopper oscillators. This is done by connecting all the SYNC pins together, mounting the oscillator RC network on one device only and grounding the OSC pin on all other devices.

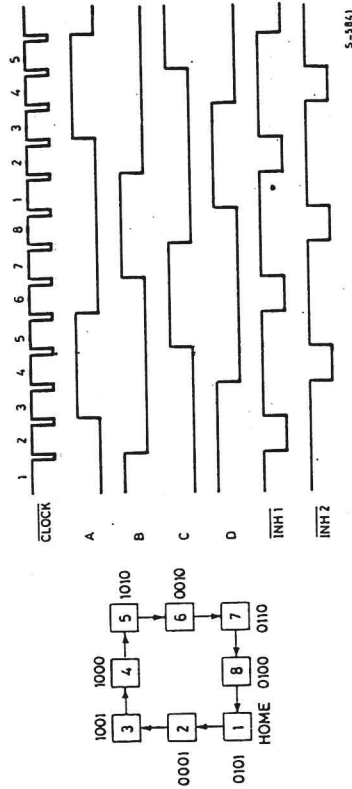
The L297A includes a pulse doubler on the step clock line which is intended to simplify the implementation of multiple stepping. A ghost pulse is generated automatically after each input pulse, delayed by the time 0.75 R_d C_d.

The RC network should be dimensioned to place the ghost pulse roughly halfway between clock pulses. If pin 1 (DOUBLER) is grounded the doubler function is disabled.

MOTOR DRIVING PHASE SEQUENCES

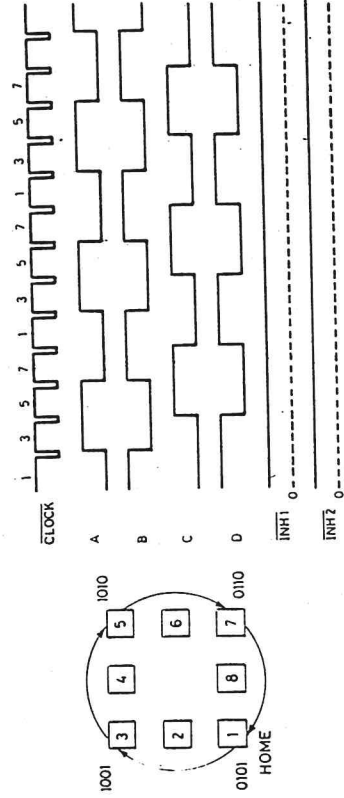
The L297's translator generates phase sequences for normal drive, wave drive and half step modes. The state sequences and output waveforms for these three modes are shown below. In all cases the translator advances on the low to high transition of CLOCK. Clockwise rotation is indicated; for anticlockwise rotation the sequences are simply reversed. RESET restores the translator to state 1, where ABCD = 0101.

Half step mode
Half step mode is selected by a high level on the HALF/FULL input.



Normal drive mode

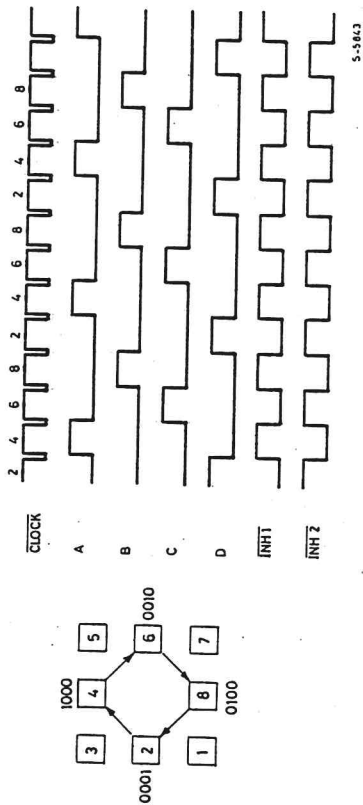
Normal drive mode (also called "two-phase-on" drive) is selected by a low level on the HALF/FULL input when the translator is at an odd numbered state (1, 3, 5 or 7). In this mode the INH1 and INH2 outputs remain high throughout.



MOTOR DRIVING PHASE SEQUENCES (continued)

Wave drive mode

Wave drive mode (also called "one-phase-on" drive) is selected by a low level on the HALF/FULL input when the translator is at an even numbered state (2, 4, 6 or 8).



5-5843

ELECTRICAL CHARACTERISTICS (Refer to the block diagram $T_{amb} = 25^{\circ}\text{C}$, $V_s = 5\text{V}$ unless otherwise specified)

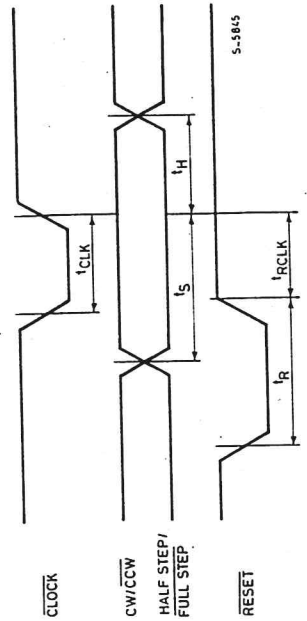
Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_s	Supply voltage (pin 12)	4.75		7	V
I_s	Quiescent supply current (pin 12)		50	80	mA
V_i	Input voltage (pins 11, 17, 18, 19, 20)			0.8	V
I_i	Input current (pin 11, 17, 18, 19, 20)			V_s	V
		$V_i = L$		-100	μA
V_{en}	Enable input voltage (pin 10)			10	μA
		Low		1.5	V
I_{en}	Enable input current (pin 10)			V_s	V
		High	2	-100	μA
		$V_{en} = L$		10	μA
		$V_{en} = H$			μA

ELECTRICAL CHARACTERISTICS (continued)

Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_o	Phase output voltage (pins 4, 6, 7, 9)			0.4	V
V_{inh}	Inhibit output voltage (pins 5, 8)			0.4	V
		$I_o = 10\text{mA}$			
		$I_o = 5\text{mA}$	3.9		
I_{leak}	Leakage current (pins 3, 11 *)			1	μA
V_{sat}	Saturation voltage (pins 3, 11 *)			0.4	V
V_{off}	Comparators offset voltage (pins 13, 14, 15)			5	mV
I_b	Comparator bias current (pins 13, 14, 15)			10	μA
V_{ref}	Input reference voltage (pin 15)			3	V
t_{CLK}	Clock time			0.5	μs
t_s	Set up time			1	μs
t_H	Hold time			4	μs
t_R	Reset time			1	μs
t_{RCLK}	Reset to clock delay			1	μs

* L297A only.

Fig. 1

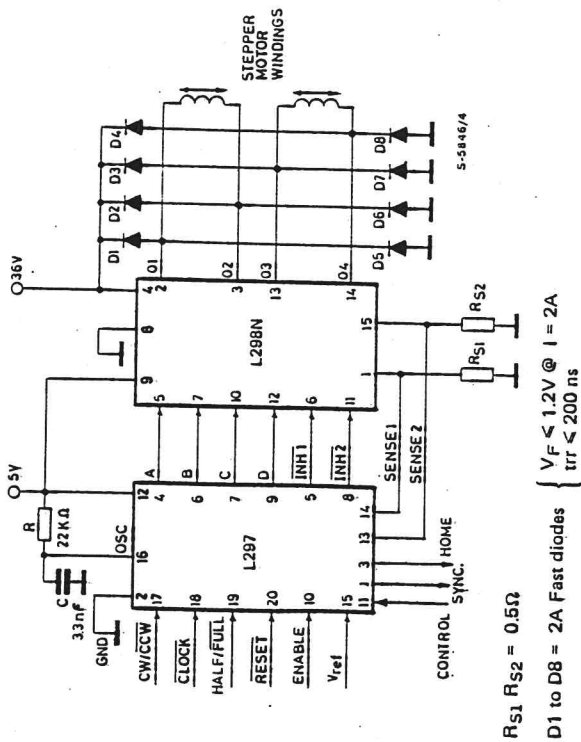


APPLICATION INFORMATION

Two phase bipolar stepper motor control circuit

This circuit drives bipolar stepper motors with winding currents up to 2A. The diodes are fast 2A types.

Fig. 2



$R_{S1} R_{S2} = 0.5\Omega$
 $D1$ to $D8 = 2A$ Fast diodes
 $V_F \leq 1.2V @ I = 2A$
 $t_{rr} \leq 200 ns$

Fig. 3 - Synchronising L297s

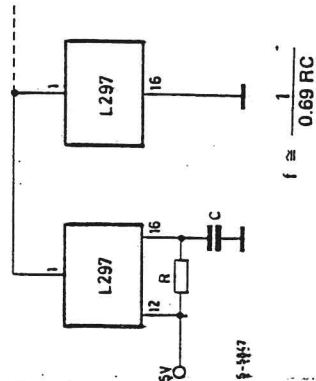
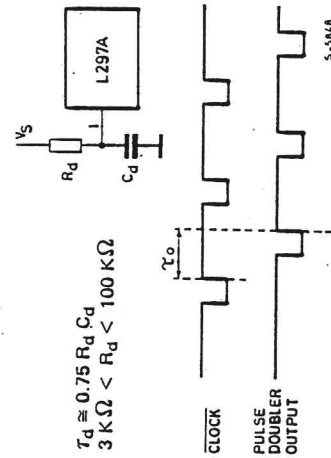


Fig. 4 - Pulse doubler (L297A)





L6203

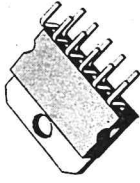
ADVANCE DATA

3A DMOS FULL BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 52V
- TOTAL DC CURRENT UP TO 3A
- LOW SATURATION VOLTAGE
- LOW POWER DISSIPATION
- NO CROSS CONDUCTION
- TTL COMPATIBLE INPUTS
- OVER TEMPERATURE PROTECTION

Each channel (half-bridge) of the device is controlled by a separate logic input, while a common enable input controls both channels. All inputs are TTL, CMOS and μ C-compatible. The L6203 is assembled in a 11-lead Multiwatt® package.

MultiPower BCD Technology

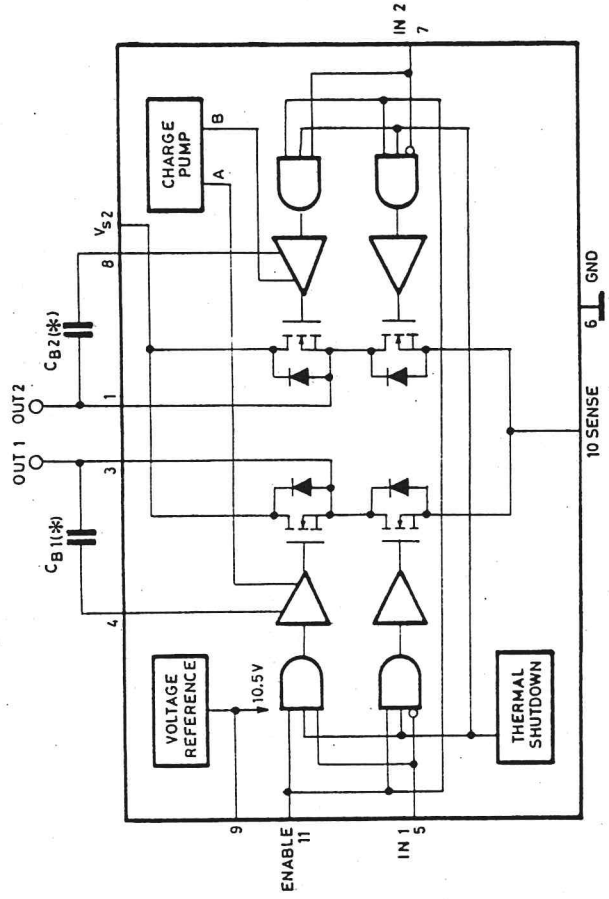


Multiwatt-11

ORDERING NUMBER: L6203

Realized with mixed bipolar/CMOS/DMOS technology, the L6203 is a full bridge driver for motor control applications. Delivering up to 3A output current at motor supply voltages up to 52V, the device uses DMOS output transistors to obtain very high efficiency and fast switching speed.

BLOCK DIAGRAM



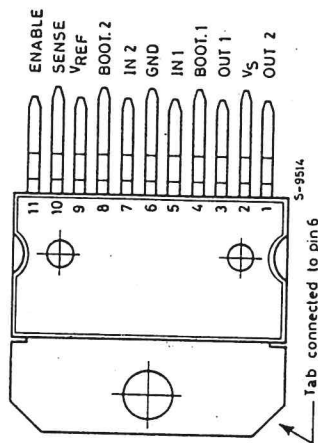
5-9520

(*) Suggested value for C_{BOOT1} and C_{BOOT2}: 10nF

This is advanced information on a new product now in development or undergoing evaluation. Details are subject to change without notice. 17/RG 570

ABSOLUTE MAXIMUM RATINGS

V_s	Power supply	60	V
V_{IN}, V_{EN}	Input or enable voltage	-0.3 to 7	V
I_o	Output current	5	A
	— peak non repetitive	3	A
	— DC operation	-1 to 4	V
V_{sens}	Sensing voltage	25	W
P_{tot}	Total power dissipation ($T_{case} = 75^\circ\text{C}$)	-40 to 150	$^\circ\text{C}$
T_{stg}, T_J	Storage and junction temperature		

CONNECTION DIAGRAM
(Top view)

PIN FUNCTIONS

N°	NAME	FUNCTION
1	OUT 2	Output of the half bridge.
2	V_s	Supply voltage.
3	OUT 1	Output of the half bridge.
4	BOOT. 1	A capacitor C_{B1} , connected to this terminal allows the upper DMOS transistor driving for high switching frequencies.
5	IN 1	Input from the controller device.
6	GND	Common ground terminal.
7	IN 2	Input from the controller device.
8	BOOT. 2	A capacitor C_{B2} , connected to this terminal allows the upper DMOS transistor driving for high switching frequencies.
9	V_{REF}	Internal reference voltage.
10	SENSE	A resistance R_{SENSE} , connected to this terminal, allows motor current control.
11	ENABLE	Enable input. A logic low level on this pin switches off the DMOS power transistors.

THERMAL DATA

$R_{th\ j-case}$	Thermal resistance junction-case	max	3	$^\circ\text{C/W}$
$R_{th\ j-amb}$	Thermal resistance junction-ambient	max	35	$^\circ\text{C/W}$

ELECTRICAL CHARACTERISTICS ($V_S = 42V$, $T_J = 25^\circ C$)

Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_S	Supply voltage	12 (*)		52	V
V_{ref}	Reference voltage		10.5		V
I_S	Quiescent supply current	$V_{EN} = H$ $I_L = 0$ $V_{IN} = L$	7		
		$V_{EN} = H$ $I_L = 0$ $V_{IN} = H$	7		mA
		$V_{EN} = L$	6		
V_{INL}	Input low voltage	-0.3		0.8	V
V_{INH}	Input high voltage	2		7	V
V_{INL}	Input low current			-10	μA
I_{INH}	Input high current		30		μA
V_{ENL}	Enable low voltage	-0.3		0.8	V
V_{ENH}	Enable high voltage	2		7	V
I_{ENL}	Enable low current			-10	μA
I_{ENH}	Enable high current		30		μA
$R_{DS(ON)}$	Saturation voltage		0.3		Ω
$V_{DS(sat)}$			0.3		V
		$I_L = 1A$			
		$I_L = 3A$			
t_1 (V _I)	Source current turn-off delay		300		ns
t_2 (V _I)	Source current fall time		200		ns
t_3 (V _I)	Source current turn-on delay		400		ns
t_4 (V _I)	Source current rise time		200		ns
t_5 (V _I)	Sink current turn-off delay		300		ns
t_6 (V _I)	Sink current fall time		200		ns
t_7 (V _I)	Sink current turn-on delay		400		ns
t_8 (V _I)	Sink current rise time		200		ns
F_C	Commutation frequency		50	100	KHz
				$I_L = 3A$	

(*) If $V_S < 12V$, $V_{ref} = V_S - 2V_{BE}$

CIRCUIT OPERATION

The L6203 is a monolithic full bridge switching motor driver realized in the new Multipower-BCD technology which allows the integration of multiple, isolated DMOS power transistors plus mixed CMOS/bipolar control circuits.

The power stage of the L6203 consists of four N-channel DMOS transistors with an $R_{DS(ON)} \cong 0.3\Omega$ over the whole current range. Each transistor has an intrinsic drain source diode. During recirculation the behaviour of these diodes depends on the operating mode.

When one of the POWER DMOS transistors is ON it behaves almost symmetrically in terms of current like, in fact, a resistor with the value $R_{DS(ON)}$ in parallel with the drain-source diode. During recirculation with the ENABLE input high, the voltage drop across the transistor is $R_{DS(ON)} \times I_L$ for voltages less than 0.7V and is clamped at a voltage depending on the characteristics of the diode for greater voltages.

When the enable input is low, the POWER MOS is off and the diode carry the whole recirculation. Although the device guarantees the absence of cross-conduction, the presence of the intrinsic diodes in the POWER MOS structure causes the generation of current spikes on the sensing pin due to charge-discharge phenomena in the reverse capacitor, C1 & C2 associated with the drain-source junctions (Fig. 1). When the output switches from high to low, a current spike is generated associated with the capacitor C1. On the low-to-high transition, a spike of the same polarity is generated by C2, preceded by a spike of the opposite polarity due to the charging of the input capacity of the lower POWER DMOS transistor (Fig. 2).

To ensure that the POWER DMOS transistors are driven correctly a gate-source voltage of about 10V must be guaranteed for all of the N-channel DMOS transistors. While there is no problem in driving the lower POWER DMOS devices (their source terminals are referred to ground) it is necessary to provide a gate voltage higher than the positive supply for the upper transistors because they have the drain connected to the supply itself.

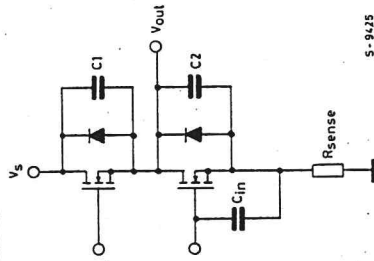
This is obtained by a system that combines a charge pump circuit, which assures correct DC operation, with a bootstrapping technique suitable for high switching frequencies.

In the bootstrap circuit the external C_B capacitors are charged to a voltage of about 10V when the upper power transistor is OFF and the

lower one is ON. To guarantee efficient driving of the upper power transistor in the conduction condition, the value of C_B must be greater than the value of the input capacitance, C_{IN} , of the power transistor itself. Since the estimated value of the input capacity is about 1nF, C_B should be $> 10nF$ to guarantee correct operation. An ON-OFF synchronization circuit provides a dead time (the period in which all four power transistors are OFF) of 40ns, sufficient to prevent simultaneous conduction with obvious advantages in terms of power dissipation and of spurious signals on the ground and in the sensing resistors.

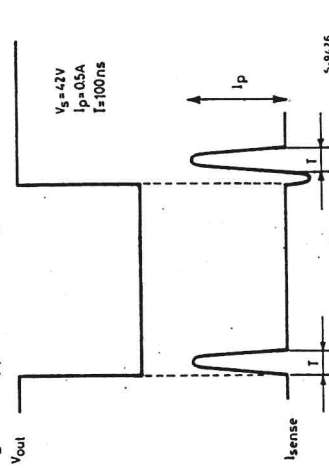
A thermal protection circuit has been included that will disable the device if the junction temperature reaches 150°C. When the temperature has fallen to a safe value the device restarts under the control of the input and enable signals.

Fig. 1 - Intrinsic structures in the POWER DMOS transistors



S-9425

Fig. 2 - Typical current spikes on the sensing pin



S-9426

Fig. 3 - $R_{DS(on)}$ vs. temperature

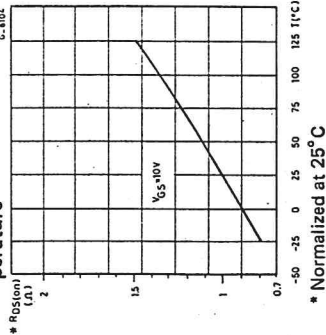
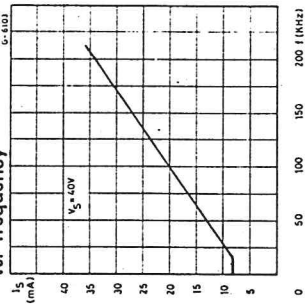
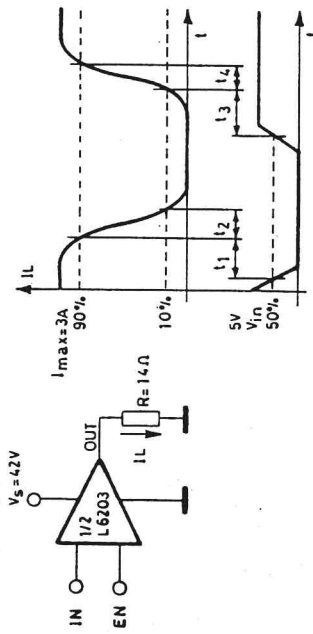


Fig. 4 - Quiescent current vs. frequency



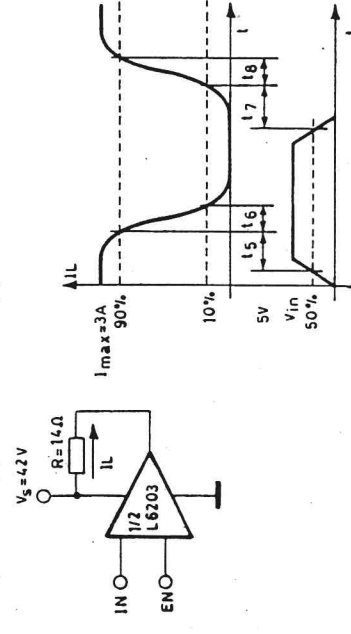
SWITCHING TIMES TEST CIRCUITS

Fig. 5 - Source current delay time vs. input or enable chopper



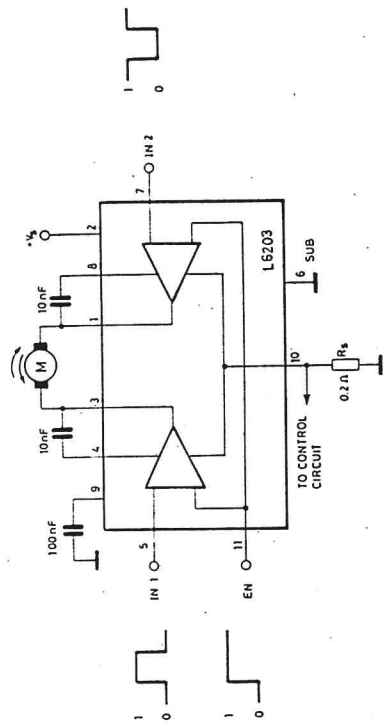
NOTE: for INPUT chopper SET EN = H

Fig. 6 - Sink current delay time vs. input or enable chopper



NOTE: for INPUT chopper SET EN = H

Fig. 7 - Bidirectional DC motor control

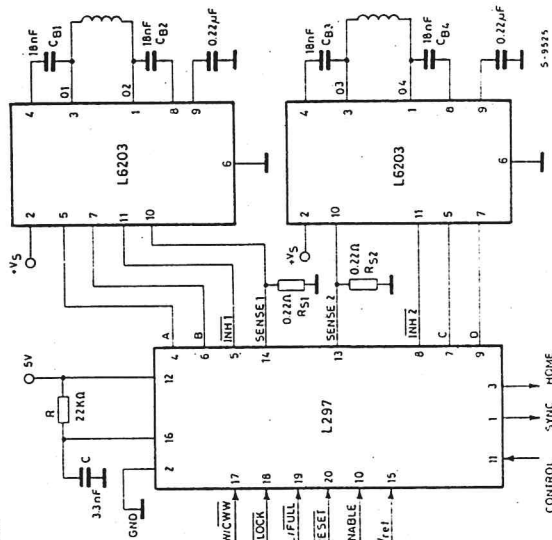


5-9521

INPUTS		FUNCTION
IN1 = H	IN2 = L	Turn right
IN1 = L	IN2 = H	Turn left
IN1 = IN2		Fast motor stop
IN1 = L	IN2 = X	Free running motor stop

L = Low H = High X = Don't care

Fig. 8 - Application circuit



5-9525

Cilindrici extracorti in custodia metallica

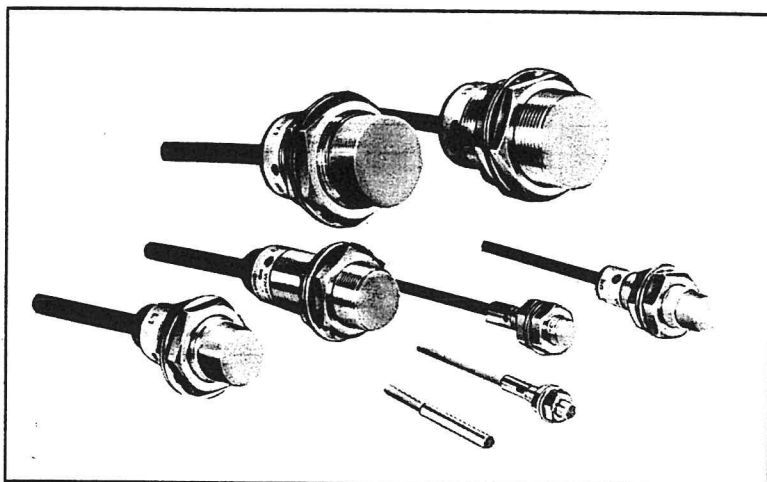
Ampio campo della tensione di alimentazione:
10 ... 30 V c.c. oppure 40 ... 264 V c.a.

Spia di funzionamento

Protezione contro cortocircuiti ed inversione di polarità per la maggior parte dei modelli in c.c.

I modelli in c.a. (tipi M18 e M30 a 110/120V c.a.) disponibili anche con protezione contro cortocircuiti

Una grande varietà di formati, incluso il ridottissimo Ø4x25mm, tutti disponibili di serie



Modelli disponibili

Modelli in c.c.

Diametro	Ø4	M5	Ø5,4	
Tipo	Schermato	Schermato	Schermato	
Distanza	0,8	1	1	
Alimentamento				
Protezione contro i cortocircuiti	NA	-CR8C1	-X1C1	-C1C1
	NC	-CR8C2	-X1C2	-C1C2
Protezione contro l'inversione di polarità	NA	-CR8B1	-X1B1	-C1B1
	NC	-CR8B2	-X1B2	-C1B2

Modelli in c.a.

Diametro		M8			M12			M18		M30	
Tipo		Schermato		Schermato	Non Schermato		Schermato	Non Schermato		Schermato	Non Schermato
Distanza di rilevamento		1,5		2	5		5	10		10	18
Protezione contro i cortocircuiti	Sprovvisto	NA	-X1R5Y1	-X2Y1	-X5MY1	-X5Y1	-X10MY1	-X10Y1	-X18MY1		
		NC	-X1R5Y2	-X2Y2	-X5MY2	-X5Y2	-X10MY2	-X10Y2	-X18MY2		
	Provvisto	NA	—	—	—	-X5Y1-53	-X10MY1-53	-X10Y1-53	-X18MY1-53		
		NC	—	—	—	-X5Y2-53	-X10MY2-53	-X10Y2-53	-X18MY2-53		

- NOTE: 1. Il tipo non schermato M8 è disponibile con distanza di rilevamento di 2 mm (E2E-X2MY□). Per informazioni più dettagliate mettersi in contatto con la nostra società.
 2. Per ordinare i modelli in c.a. conformi alle norme UL e CSA aggiungere il suffisso "-US".

Caratteristiche tecniche

Modelli in c.c.

Tipo	NPN	E2E-CR8C□	E2E-X1C□	E2E-C1C□
	PNP	E2E-CR8B□	E2E-X1B□	E2E-C1B□
Alimentazione (campo tensione di funzionamento)	12 ... 24 V c.c. (10 ... 30 V c.c.)			
Assorbimento	10mA max.			
Oggetto	Metalli ferrosi			
Distanza di rilevamento	0,8mm ±15%	1mm ±15%		
Campo distanza di rilevamento (con oggetto standard)	0 ... 0,5mm (Ferro: 5x5x1t)	0 ... 0,7mm (Ferro: 5x5x1t)		
Distanza differenziale	15% max. della distanza di rilevamento			
Frequenza di azionamento	3kHz			
Uscita	100mA max.			
Protezione contro cortocircuiti	No			
Spia	Spia di rilevamento			
Lunghezza del cavo	2m			
Materiale della custodia	Ottone nickelato			
Grado di protezione	IP67 (IEC 144), NEMA tipi 1, 4, 6, 12, 13.			

Modelli in c.a.

Tipo	Generale	E2E-X1R5Y□	E2E-X2Y□	E2E-X5Y□	E2E-X5MY□	E2E-X10Y□	E2E-X10MY□	E2E-X18MY□
	Con protezione contro cortocircuiti	—	—	E2E-X5Y□-53-G	—	E2E-X10Y□-53-G	E2E-X10MY□-53-G	E2E-X18MY□-53-G
Alimentazione (campo tensione di funzionamento)	Generale	42 ... 240 V c.a. (40 ... 264 V c.a.)						
	Con protezione contro cortocircuiti	100 ... 120 V c.a. (90 ... 140 V c.a.)						
Corrente residua	1,5mA a 140 V c.a.							
Oggetto	Metalli ferrosi							
Distanza di rilevamento	1,5mm ±10%	2mm ±10%	5mm ±10%	5mm ±10%	10mm ±10%	18mm ±10%		
Campo distanza di rilevamento (con oggetto standard)	0 ... 1,2mm (Ferro: 8x8x1t)	0 ... 1,6mm (Ferro: 12x12x1t)	0 ... 4mm (Ferro: 18x18x1t)	0 ... 4mm (Ferro: 15x15x1t)	0 ... 8mm (Ferro: 30x30x1t)	0 ... 14mm (Ferro: 54x54x1t)		
Distanza differenziale	10% max. della distanza di rilevamento							
Frequenza di azionamento	25Hz							
Uscita	Generale	5 ... 100mA	5 ... 300mA a -25 ... +70°C 5 ... 500mA a -25 ... +55°C	5 ... 100mA	5 ... 300mA a -25 ... +70°C 5 ... 500mA a -25 ... +55°C			
	Con protezione contro cortocircuiti	—	5 ... 300mA	—	5 ... 300mA			
Protezione contro cortocircuiti	Provvisto solamente per modelli E2E-X□Y□-53-G							
Spia	Spia di funzionamento							
Lunghezza del cavo	2m							
Materiale della custodia	Ottone nickelato							
Grado di protezione	IP67 (IEC 144), NEMA tipi 1, 4, 6, 12, 13							

Caratteristiche generali

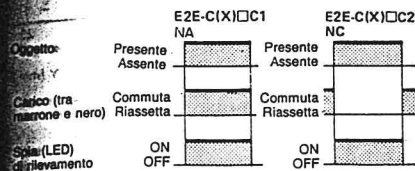
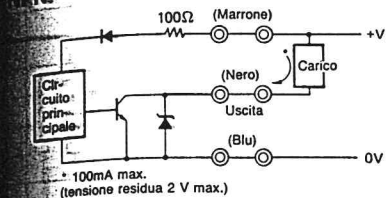
Tipo	E2E-CR8	E2E-C(X)1	E2E-X1R5	E2E-X2	E2E-X5	E2E-X10	E2E-X5M	E2E-X10M	E2E-X18M
Scostamento alle variazioni della temperatura	Tipi diam. 4, diam. 5,4 e M5: da -25 a +70°C: ±15% max. della distanza di rilevamento misurata a 23°C Altri: da -25 a +70°C: ±10% max. della distanza di rivelamento misurata a 23°C								
Scostamento alle variazioni della tensione	Modelli in c.c.: a ± 15% max. della tensione nominale: ±2,5% max. della distanza di rilevamento Modelli in c.a.: a ±10% max. della tensione nominale: ±1% max. della distanza di rilevamento								
Corrente residua	Ved. "Curve caratteristiche corrente residua"(modelli in c.a. solamente)								
Tensione residua	Ved. "Schemi circuiti di uscita" oppure "Curve caratteristiche tensione residua del carico"								
Isolamento	50MΩ min. a 500 V c.c.								
Rigidità dielettrica	Modelli in c.c.: tipi diam. 4, diam. 5,4 e M5: 500 V c.a., 50/60Hz per 1 minuto Altri: 1.000 V c.a., 50/60Hz per 1 minuto Modelli in c.a.: tipo M8: 2.000 V c.a. 50/60Hz per 1 minuto Altri: 4.000 V c.a.: 50/60Hz per 1 minuto								
Resistenza alle vibrazioni	1,5mm doppia ampiezza con 10 ... 55Hz								
Resistenza agli urti	500m/s ² (50G circa)			1000m/s ² (100G circa)		500m/s ² (50G circa)		1000m/s ² (100G circa)	
Temperatura ambiente	-25 ... +70°C								
Umidità ambiente	35 ... 95% U.R.								
Peso	30g circa	30g circa	45g circa	120g circa	160g circa	270g circa	120g circa	160g circa	270g circa

Il peso comprende il cavo di 2m.

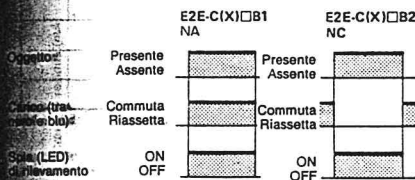
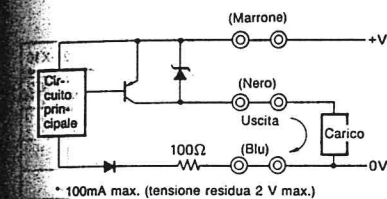
Schemi circuiti di uscita

Modelli in c.c.

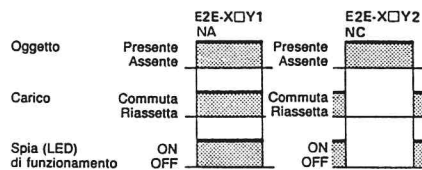
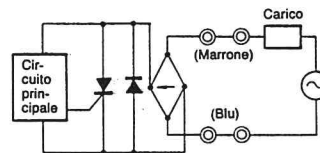
VRN



RNP



Modelli in c.a.



Curve caratteristiche

Campo di rilevamento

E2E-CR8□□, E2E-X1□□, E2E-C1□□

E2E-X1R5□□, E2E-X2□□

